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A comparison of reliability prediction methodologies to observed field failure data

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A COMPARISON OF RELIABILITY PREDICTION METHODOLOGIES TO OBSERVED FIELD FAILURE DATA

or

FOUR TO DOOMSDAY

by

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A Comparison of Reliability Prediction Methodologies To Observed Field Failure Data

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ABSTRACT

Reliability predictions of electronic equipment are considered highly valuable; yet the most widely used technique, Military Handbook 217 is criticized as inaccurate. The industry response to the Handbook has been to develop a myriad of methodologies for failure rate prediction.

This paper uses four (4) reliability prediction methods to forecast the failure rate of two (2) circuit boards for which a field failure history exists. The predicted failure rate for each procedure on each board is compared to the actual failure rate; and a first-order correction factor is calculated.

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I. INTRODUCTION

A. Failure Rate Prediction Utility

The study of electronic component reliability has been an ongoing process since the devices first appeared [1]. However, the increasing performance demands made by the marketplace on systems has interpreted reliability as an integral and fundamental part of product integrity [2,3]. A product's reliability can be assessed by testing; but this is impractical since by the time a weakness is discovered, the system is already in production. The subsequent constraints on design modifications would hamper many improvements. The preferred method by which system reliability is assessed is by prediction.

There are several predictive methods for reliability assessment, the most popular of which is Mil-Hdbk-217 [4]. Called the 'bible of electronic component failure rate data', its use is often a contract requirement for new designs [5]. The intensive efforts to update and maintain the currency of its databases leads to widespread application of its predictive computations. Almost 40 billion hours of circuit testing was performed to provide additional verification of the models contained in the handbook [6]. The failure rate model used most frequently in the

Mil-Hdbk-217E version for monolithic microelectronic devices is:

$$\text{Lambda} = \pi_Q*(C_1*\pi_T*\pi_V + C_2*\pi_E)*\pi_L \quad \text{failures}/10^6 \text{ hours} \quad (1)$$

Where: Lambda = The failure rate of the device

π_Q = The Quality Factor, associated with compliance to military standards and requirements.

C_1 = The circuit complexity factor, based on the number of gates or transistors and the technology employed.

π_T = The Temperature Acceleration Factor, determined through an Arrhenius relationship between temperature and failure rate.

C_2 = The packaging complexity failure rate.

π_E = The application Environment Factor.

π_L = The Device Learning Factor; based on the newness of the process which manufactures the parts.

π_V = The Voltage Stress Derating Factor

This model has been employed for over 10 years in the Handbook to represent integrated circuit failure rates. Yet, the reliability estimates of Mil-Hdbk-217E have not been confirmed by observation. The Handbook is invariably pessimistic in its predictions [5,8,10]. This has led to much criticism of Mil-Hdbk-217.

B. What's Wrong with Mil-Hdbk-217E?

1. Temperature Acceleration Factor Deficiency

The most persistent criticism with Mil-Hdbk-217 concerns the generation of the temperature acceleration factor, an empirical relationship based upon the regression of failure data [7]. Blanks [5] points out that the range of activation energies of the various possible failure mechanisms in monolithic circuits is so wide, that relating failure rate to temperature dependence is virtually impossible. Smith [8] asserts that the testing of military specification units to determine the model parameters, plus the use of an incorrect reference temperature cause erroneous π_T values.

Indeed, an examination of the calculations resulting in the π_T factors bases the junction temperature on the case temperature plus the product of the component power consumption times its junction-to-case thermal resistance (θ_{J-C}). But the device power is dissipated through two thermal resistances, the junction-to-case, and the case-to-ambient (θ_{C-A}). Ignoring θ_{C-A}

(which may vary by more than 2 orders of magnitude, depending on the application), assumes an infinite case heat sink. Much more practical is using the sum of the thermal resistances to dissipate the generated power into an ambient heat sink to compute the junction temperature [9], or

$$\text{Junction Temperature} = \text{Generated Power} * (\theta_{J-C} + \theta_{C-A}) \quad (2)$$

2. Other Criticisms of Mil-Hdbk-217E

In addition to the temperature acceleration factor deficiencies, other features of Mil-Hdbk-217 have been critiqued. Shen [10] reports that factors other than parts failures account for a majority of the total failures occurring in demonstration and verification tests. Blanks questions the independence of the π factors. He states "At the simplest it seems certain that high-quality components are less vulnerable to the various environment-related stresses than are lower quality ones and that the ratio of failure rate in any given non-benign environment to that in 'benign ground' is smaller for high-quality than for lower-quality product. Instead of the π_E values being independent of quality they should therefore decrease with increasing quality."[1].

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1. Blanks, op. cit., page 229.

While the derivation of π_T is often singled out, O'Conner[7] states the major difficulty with Mil-Hdbk-217 most succinctly. He points out that system level considerations such as, inadequate design, unsatisfactory handling, and environmental aspects not covered by part-level formulas (vibration, humidity, switching effects, etc.) are simply not addressed by the models in Mil-Hdbk-217. Shen concurs by stating that "Design engineering, design acceptance, incoming and outgoing QA, manufacturing control and organizational dynamics are equally important in terms of reliability contributions"[2]. That component reliability estimates are generated <u>before</u> their assembly

into a system was noted by Usher, Alexander, and Thompson [11]. They correctly reveal that any non-component related failure mechanism would not be accounted for in the component reliability estimates.

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2. Shen, op. cit., page 534.

C. Approaches Taken to Address These Discrepancies

Since forecasts are still highly desirable, several different attempts have been made to deal with the reliability prediction process. One of the simplest approaches was performed by Seidl and Garry [12]; in which they derived π_Q, π_L, and π_E factors by using a different set of data than did Mil-Hdbk-217E. They assert that analysis of data supplied by the Semiconductor Industry Association's Government Procurement Committee provides more realistic and updated π factors than does the Handbook. Pantic [13] modifies the Handbook predictions by adding technology and manufacturer maturity factors to the traditional Mil-Hdbk-217 models.

At Bell Communications Research Inc., the discrepancy between Mil-Hdbk-217 and observed failure rates had not gone unnoticed. Their response, reported by Healy [14], and furthered by Beltrano [15] at AT&T Laboratories, was to derive their own failure rate models (again, based on regression from field performance data). This effort has culminated in what is, in effect, an alternate for Mil-Hdbk-217E; the AT&T Reliability Manual [16]. This manual provides a process by which the reliability of a group of components can be individually calculated, then summed to provide an estimate of the system represented.

As before, a separate set of data than that which led to the models and coefficients in Mil-Hdbk-217E has led to a separate model.

Not unexpectedly, the variety of methodologies results in a variety of reliability predictions. In his seminal study, Spencer [17] compared a prediction using Mil-Hdbk-217 to procedures developed by four telecommunications companies. His results showed a variation between predictions of greater than a factor of 6000. Clearly, one or more of the techniques is not a good predictor. Spencer did not follow-up his study by determining the actual failure rate of his example memory board. If he had, he would have been able to determine which of the five methods was the best predictor. Alternatively, a correction factor could have been determined to adjust the predictions towards the realized failure rate. Such a correction factor will become part of the reliability predictions generated in this study.

Two studies have been performed in which observed failure rates have been compared to their predicted values. Murphy [18] noted that the Mil-Hdbk-217D prediction overestimated the failure rate of his hybrid system by a factor of 2.7. Webster [19] calculated the predicted failure rate of 21 subsystems using Mil-Hdbk-217D; then accumulated failure data and determined the MTBF of his modules. Webster's MTBF values were much lower than the corresponding prediction; so much so that even the upper limit of 90% confidence interval for each MTBF was less than the Mil-Hdbk-217 prediction.

D. A Proposed Evaluation of Reliability Prediction Models

By itself, Mil-Hdbk-217 has been shown to be inaccurate in predicting the realized reliability of systems. However, the available alternatives to Mil-Hdbk-217 have not undergone as public an examination as the Handbook. The objective of this study is to test Mil-Hdbk-217E plus its modifications and alternatives with two circuit board subsystems for which actual failure data exists. The failure rate of each circuit board will be predicted using four techniques. They are:

- Mil-Hdbk-217E, strictly applied
- The Seidl and Garry Modified π-Factor Approach
- The AT&T Reliability Manual
- A Dynamic Reliability Model, Using Manufacturer's Failure Rate Data.

Each failure rate prediction shall be compared to the observed failure rate; and a linear correction factor K_x shall be determined for each method. These correction factors are one of the most important products of this study. Since improved reliability prediction capability is the ultimate goal, using the K_x factor with its 'parent' methodology provides a first-order match to all the internal biases and offsets. In effect, the methodology is custom-fit to our particular technology and operations; and can be employed with confidence on other circuit boards manufactured in a similar manner.

If all of the K_x factors are equal to 1.0, there is no deviation of the prediction from the observed failure rates. Any non-unity K_x factor does indicate a difference between prediction and reality. In the event of such an occurrence, a discussion of the discrepancies between the predictions and observations will follow.

Reliability predictions have the distinction of being praised as worthwhile and criticized as incomplete at the same time. The wide application of Mil-Hdbk-217 does not reconcile its weaknesses with regards to the calculation of the temperature acceleration factor and its lack of consideration for design, manufacturing, and production contributors to the failure rate. Understandably, those interested in reliability predictions have adopted a variety of approaches towards calculating failure rates prior to the availability of data. This paper proposes to compare four (4) methodologies, Mil-Hdbk-217E, The Seidl and Garry Modified π-Factor Approach, The AT&T Reliability Manual, and a dynamic model using manufacturer's test data on two (2) circuit boards. First-order, correction factors will be calculated to correct future predictions using the same technique.

II. CIRCUIT BOARD SELECTION & PREDICTION METHOD DESCRIPTION

A. Selection of the Test Circuit Boards

The previously selected reliability prediction techniques are undergoing evaluation with an unambiguous test: comparison of their estimates with field failure data. Such a comparison requires that the observed failure rate of the subsystems be a good representation of a long-term failure rate process, not infant mortality or some other effect. The components chosen for appraisal should also represent a variety of technologies so that a sensitivity by a prediction method to one type of device (memory, analog, etc.) does not introduce undue bias. Therefore, care must be taken in the selection of the subsystems used in the evaluation. Fortunately, good candidate devices exist in the KODAK EKTACHEM family of Blood Analyzers.

An Ektachem Blood Analyzer, manufactured by Eastman Kodak Company, is an integrated hardware, software, and chemistry machine used by clinical laboratories in the determination of concentrations of proteins, electrolytes, and other materials in blood samples. The family of analyzers range from desk-top models to large, free-standing 'mainframe' units. Two circuit boards from an Ektachem analyzer have been chosen for this study. For proprietary reasons, the boards shall be called Circuit Board A (CBA) and Circuit Board B (CBB). During the data collection period of the study, CBA was present in the field in two versions, one of which contained additional components. Both versions of CBA are included in the analyses.

The circuit board assemblies contain a combination of analog, digital, discrete semiconductor, and passive components on a multi-plane printed circuit board. Commercially available parts and standard manufacturing technologies were employed in their manufacture. The circuit boards have been in continuous production for many years before the data collection period in order to avoid any infant mortality effects or design overstresses prejudicing the field failure data. A complete list of the components used in each circuit board can be found in Appendix A.

The ambient environment for the circuit boards is well known. The analyzer model from which these subassemblies come resides in climate-controlled laboratories in the United States. Filtered input power, a stable, level mounting, and adequate cooling air provision are specified for each installation. Each analyzer is serviced on a "preventative" and an "as needed" basis. Records are kept regarding what actions and parts replacements were performed during each service call. Measurements have been made concerning the temperature rise above outside ambient for the air circulating around the two circuit boards. The data indicates that there is a 10° C. rise above ambient in the vicinity of our devices. Thus, with a normal environment of 25° C., the temperature of the air around CBA and CBB shall be considered to be 35° C.

B. Failure Rate Determination

Failure rate data were collected for the years 1989 and 1990 from the installed base of analyzers. The total number of operating hours of CBA and CBB was determined as follows. For each month during the two year period, the total number of analyzers was ascertained. Then, the average number of operating hours for each analyzer was calculated by subtracting the average service and maintenance time from the total hours in the month (it is customary to operate the Ektachem analyzer 24 hours a day, seven days a week). The average service and maintenance time is computed by multiplying the yearly number of service and maintenance calls by their average duration, then dividing by twelve. The product of the average number of operating hours times the number of analyzers in service during a given month equals the total operating hours for CBA and CBB. The summation over the twenty-four month data collection period determines the time period over which the failures of CBA and CBB occurred.

Thus,

$$\text{Avg. Monthly Service Time} = (\text{Number of Service Calls}) * (\text{Average Call Duration}) / 12 \quad (3)$$

$$TOH = \sum_{i=1}^{24} (\text{Hours / Month} - \text{Avg. Monthly Service Time}) * (\text{Installed Base of Ektachem Analyzers})_i \quad (4)$$

where TOH = Total Operating Hours of CBA and CBB.

Records on the number of circuit board A and B replacements during the data collection period have been kept by Eastman Kodak's Customer Equipment Service Division (CESD). Those replacements includes some circuit boards which are not defective. With analyzer availability being very highly valued by the customer, the service personnel often perform several actions concurrently when responding to a service call. Consequently, an adjustment is required to transform the number of circuit board returns into a better estimate of actual CBA and CBB failure rates. An analysis of the circuit boards returned by CESD over the year 1990 indicated that between 60% and 70% of the subassemblies contained a failed component [20]. For the purposes of this study, the value of 65% of the returned CBAs and CBBs possessing a failure shall be used.

C. Model Descriptions

For each prediction method, a series reliability model of each circuit board has been derived. Those components on the circuit board whose failure does not adversely affect performance (i.e., indicator LEDs) are not included in the model. Otherwise, the failure of any component is considered as a failure of the assembly. The failure rate of each component included in the prediction method under study is calculated, then summed with the other component failure rates to determine the failure rate of the entire assembly. The use of a series reliability model for CBA and CBB simplifies the task of each prediction method into one of determining the individual failure rates for a specified set of components.

Before continuing, a few words are required concerning the rush to employ a series reliability model. A series model is a good approximation of a system in many cases; but the limitations of the series approach need to be understood. The series model does not take any duty cycle effects into account. A CMOS device, for example, may have very low power consumption (and low junction temperatures) during periods in which its switching frequency is low. The same device may consume much more energy, thus raising its junction temperatures and shortening its expected life if the switching frequency is high. The series model does not adjust for this. Consequently, if a subpopulation of assemblies is operated at high switching rates by their users, the model will not adequately predict this groups mean time between failures.

Another difficulty with the series model is the lack of any criticality factors associated with the devices. The model assumes that all devices are equally necessary for operation, else the system has failed. In reality, some of the components are utilized for only a subset of the total functions performed. Their failure represents a degraded system functionality, not a complete shutdown. Other factors, such as the use of preventative maintenance, and the extent of failure (catastrophic, major, minor, etc.) are not considered in the use of a series model.

Thus, the advantage of a simplified set of calculations is counterbalanced by a less realistic version of the physical system described by the series reliability model. The model is an approximation of the real world, not an exact description of it.

1. Mil-Hdbk-217E

The "Parts Stress Analysis" version of Mil-Hdbk-217E has been employed to predict the failure rates of CBA and CBB. The crystals employed on our circuit boards are the only devices whose models have changed from Mil-Hdbk-217D. Thus, earlier concerns of Mil-Hdbk-217D found in the literature remain valid. For each component of CBA and CBB, the appropriate operating model of the Handbook was evaluated for the particular characteristics (power, number of output pins, circuit complexity, etc.). Several factors are common to all or almost all of the parts on the boards they are:

$\pi_Q = 20.0$ (Commercial Quality parts)

$\pi_V = 1.0$ (Most CMOS parts were operated at +5 Volts)

$\pi_E = 0.38$ (Benign Ground for all the components)

$\pi_L = 1.0$ (No new technology or initial production devices were used on CBA or CBB).

The Mil-Hdbk-217E series reliability models for CBA and CBB include every component on the circuit board considered necessary for their function. Every resistor, capacitor, socket, crystal, etc., has had its failure rate calculated by the processes denoted in the Handbook. The calculations were performed using the Lotus 1-2-3 spreadsheet program. Appendix B contains a printout of the complete set of computations. The listing of the equation inputs to each cell can be obtained by contacting the author.

An examination of the prediction results shows that the significant majority of the expected failures for CBA and CBB are attributed to the integrated circuits. Over 90% of the expected failures on CBA, and over 95% of the expected failures of CBB are assigned to the monolithic devices. Including the remaining components into the prediction results in only a marginal change in the final value.

This observation allows simplification of the other models to series combinations of the integrated circuits only. The rationale for this is as follows. The models contained in the Mil-Hdbk-217E are based upon regressions with failure data. The Seidl and Garry approach, and the models in the AT&T Reliability Manual are also based on field data regression; albeit different data were used in the regressions. The dynamic reliability model's data comes from tests on devices specific to CBA and CBB, which are also devices included in the field data used by the other models. In essence, similar data are being interpreted and modeled differently in each of the prediction methods under study. Each model must approximately 'fit' its own data set to be considered useful. With approximately the same data being fitted to approximately the same goodness-of-fit, relative relationships between classes of components should be consistent across the methodologies. This assumption will be put to the test in a later section.

By implication, components which have very high reliability in the Mil-Hdbk-217 prediction should maintain their relative reliability relationships with the other techniques. This assumption of consistent relative failure rates across the procedures simplifies the three remaining models from almost 300 items to a series combination of 50 components.

2. Seidl and Garry Modified π-Factor Approach

Seidl and Garry, under contract to the Rome Air Development Center (RADC) examined the failure data from the Microcircuit Device Reliability (specifically, MDR-21 and MDR-22) reports published by the RADC Reliability Analysis Center. Their analysis resulted in new values of π_Q (the quality factor), π_L (the learning factor), and π_E (the environmental factor). A brief description of each new π factor is provided. For full details of their derivation, consult Reference 12.

Instead of reflecting differences in part qualification, screening, procurement practices, and materials, Seidl and Garry capitalized upon the correlation between the amount of screening performed and the ultimate field reliability. They computed 'weighting factors' by normalizing the percentage contribution of each failure mechanism to sum to 100. Each weighting factor contained in the screening methods associated with the S, B, D, and D-1 quality levels was totaled to create a 'screening factor'. Each screening method's factor grew as the number of failure mechanisms for which it tested increased. By fitting S-level and B-level burn-in values to curves derived from Mil-Std-883, an inverse relationship between screening factor and π_Q was developed; and is

$$\pi_Q = 71.3 \,/\, \text{Screening Factor}. \qquad (5)$$

The π_L factor in Mil-Hdbk-217E was redefined by Seidl and Garry as a modifier of early life IC failure rates, and not as a factor in predicting long term reliability. Data from the Semiconductor Industry Association Government Procurement Committee was regressed as ln(defective parts per million) vs time.

Normalizing the assumed mature product 100 defective PPM level to 1.0, the expression for the modified learning factor for early life failures becomes

$$\pi_L = 0.01 * Exp(5.35 - 0.35\ Y) \qquad (6)$$

where Y is years of production of the device.

For our purposes, where the long term failure rate is the item of interest, the modified π_L is not appropriate. Thus the value of 1.0 shall be used in the calculations.

Seidl and Garry reduced the number of environmental factors by grouping factors based on equipment classification and expected case operating temperature, a factor previously noted as having a large impact on reliability. Once grouped, the geometric mean of the current Mil-Hdbk-217E value for each member was calculated and assigned as a global environmental factor for each environment included in the group. For our study, Benign Ground was combined with Missile Silo Ground; and a new π_E factor of 0.5 was calculated.

Appendix C contains the full evaluation of CBA and CBB using the modified π-factors. Like the Mil-Hdbk-217E prediction, the calculations were compiled on a Lotus 1-2-3 spreadsheet.

3. AT&T Reliability Manual

The AT&T Reliability Manual is the publication of a process which has been ongoing since the late 1950's. Populations of components have been analyzed probabilistically; and their average lifetimes predicted. AT&T's electronic device hazard rate model contains two regions: infant mortality and steady-state reliability. Infant mortality is characterized by a decreasing failure rate with time, with the steady-state region being distinguished by a constant failure rate $Lambda_L$. The AT&T reliability model designates the first 10^4 hours of operation of a device the infant mortality period. Failures after about 1 year of continuous operation are considered steady-state failures. Currently AT&T categorizes their parts into Level I, II, or III classes based on the amount of qualification testing.

AT&T employs accelerated testing in the characterization of their devices. The calculation of an acceleration factor A_T, uses an Arrhenius relationship with the activation energy E_a, specified by the device technology. For example, Bipolar components are assigned an E_a of 0.4 eV; and MOS devices are assigned an E_a of 0.5 eV.

The reliability model also differentiates between permanent structures which are environmentally controlled, and three other types (non environmentally controlled structures, manholes &

poles, and vehicular-mounted). The Ektachem analyzer is sited at environmentally controlled locations, which leads to and Environment Application Factor E of 1.0.

The final modifier of the failure rate is a Hazard Rate Multiplier (HRM) that relates the long-term failure rate of one device to the failure rate of similar devices which are of a different reliability classification. By using the HRM, the steady-state failure rate of a device, which has not been evaluated by AT&T, can be estimated by multiplying the similar hermetically sealed Level III part by the appropriate HRM. Multiple applications of HRMs (either by division or multiplication) can estimate the hazard rate of Level I or II parts based on data from Level II or I parts.

With the above in mind, the AT&T failure rate for a device is given by

$$\text{Lambda}_{device} = A_T * \text{Lambda}_L * HRM \qquad (7)$$

with the predicted failure rate of a system being designated by

$$\text{Lambda}_{system} = E\ \Sigma\ (A_T * \text{Lambda}_L * HRM). \qquad (8)$$

Appendix D (another Lotus 1-2-3 spreadsheet) contains the detailed calculations of CBA and CBB series reliability models of the integrated circuits using the AT&T Reliability Manual. Not included in Appendix D, but evaluated in parallel with the models are predictions of the failure rates of the remaining active and passive components of CBA and CBB. This was done in order to test our assumption of the relative magnitudes of the failure rates of the integrated circuits compared to all the other components on the circuit boards. Interestingly, the predicted failure rate of these components was approximately 5% of the predicted failure rate of the integrated circuits on their respective board. This serves to justify the simplification of the non Mil-Hdbk-217E reliability models to include only the integrated circuits.

4. Dynamic Reliability Model Using Manufacturer Data

One of the risks entailed when the previous failure rate prediction techniques are employed, is that the data which generated the models and coefficients contained therein has become outmoded due to the advances in the state of the technology. It is hard to imagine a science in which the development rate has been as rapid as that occurring in monolithic devices. While the 40 billion hours of circuit testing mentioned earlier is an impressive accomplishment, in only a few years, that data will be considered obsolete and irrelevant. An alternative to using data collected years ago is to employ data collected today.

The final prediction technique in our study is a dynamic series reliability model utilizing current failure rate data from the manufacturers producing the devices. Realizing the importance of reliability to their customers, the fabricators of integrated circuits engage in extensive, continuous testing as a means of controlling and improving their manufacturing processes. The failure data from accelerated temperature testing is usually compiled quarterly. This information is cheerfully provided to almost anyone who asks. Often, it is possible to obtain statistically significant failure rate data on the exact device employed in your application.

Armed with the failure rate data, the activation energy of the device type (also supplied by the manufacturer), and the temperature at which the testing occurred, a predicted failure rate for the component as you apply it can be derived by multiplying the observed high-temperature mean time to fail (MTTF) by an Arrhenius-based acceleration factor; or

$$Lambda_{device} = MTTF * A_T \quad (9)$$

with $A_T = \exp[E_a / K_B * (1/T_{application} - 1/T_{Tested})]$

where T = Temperature in degrees Kelvin

K_B = Boltzmann's Constant, 8.617×10^{-5} eV/deg K

The application of an Arrhenius acceleration factor is proper in this case due to the narrow temperature range over which the parts are tested relative to the temperature at which the apparatus functions. At very high or very low temperatures, other effects (increased gap energy required for semiconductor function, or chemical breakdown of the device, for example) dominate the performance of the component. Extrapolating the Arrhenius relationship into these regions is inappropriate. However, the use of the relationship in the 35° C to 125° C range is valid.

The integrated circuits of CBA and CBB were ordered into series reliability models. Temperature, activation energy, and failure data were obtained from four integrated circuit manufacturers: Texas Instrument [21, 22, 23], National Semiconductor [24], Motorola Inc. [25, 26], and Intel Corporation [27]. With the utilization of the temperature acceleration factor, the predicted failure rate of the components of each model were determined. Where information from multiple manufacturers led to redundant failure rates, the average of these rates were included in the calculations.

The predicted failure rate of the circuit board is defined as the sum of the component failure rates. Appendix E contains the tabulated and calculated failure rate information.

Two circuit boards were chosen from a commercial blood analyzer; and their failure rate for a two-year period was determined. The components from these boards were input into each of the four (4) failure rate prediction approaches, resulting in four reliability forecasts. Series reliability models, despite their limitations, were employed for each model. Thus, each board failure rate calculation is a summation of component random failure rates.

III. RESULTS

A. Calculation of Field Failure Rates

Data from the years 1989 and 1990 were collected on the returned CBAs and CBBs from the field. That data were adjusted by the 65% correction factor attributed to the return of non-failed circuit boards. During that period, the total number of Ektachem Analyzers containing CBA and CBB were recorded on a monthly basis. The number of service calls and their duration for the population of analyzers was accumulated for the two-year period and subtracted from the number of hours in each month to determine the average on-time of the analyzer (according to equation 3). Using equation 4, the total operating hours of CBA and CBB were calculated to be:

$$\underline{TOH = 19{,}367{,}927 \text{ Hours}} \tag{10}$$

During 1989 and 1990, the following field returns were recorded:

$$\text{CBA Returns} = 232 * 65\% = 151 \text{ Failed Assemblies} \tag{11}$$

$$\text{CBB Returns} = 282 * 65\% = 183 \text{ Failed Assemblies} \tag{12}$$

Applying equations 10, 11, and 12, the failure rates of CBA and CBB for the period in question are:

<u>CBA Failure Rate = 7.786 Failures / Million Hours</u>

<u>CBB Failure Rate = 9.464 Failures / Million Hours</u>

The CBA and CBB failure rate values will be compared to the predictive results of the four series reliability models.

B. Prediction Methodology Results

Using the four techniques outlined in the previous chapter, the predicted failure rates of CBA and CBB were calculated (the calculated values are contained in Appendices B through E). The consequences of those calculations are summarized in Table I below. The calculation of the linear correction factor K, rectifying the discrepancy between the predicted and observed failure rates is listed in Table II. Graphical representations of the predicted failure rates and correction factors follows.

Table I. Predicted Failure Rates of CBA and CBB

	Failures per Million Hours of Operation	
Prediction Method	CBA	CBB
Mil-Hdbk-217E	17.640	11.982
Modified π-Factors	6.273	3.521
AT&T Reliability Manual	5.905	4.022
Manufacturers' Data	5.919	3.931

Table II. Prediction Method Correction Factor K_x

Prediction Method	CBA	CBB
Mil-Hdbk-217E	0.441	0.790
Modified π-Factors	1.241	2.688
AT&T Reliability Manual	1.319	2.353
Manufacturers' Data	1.315	2.408

Figure 1, Failure Rate Differences

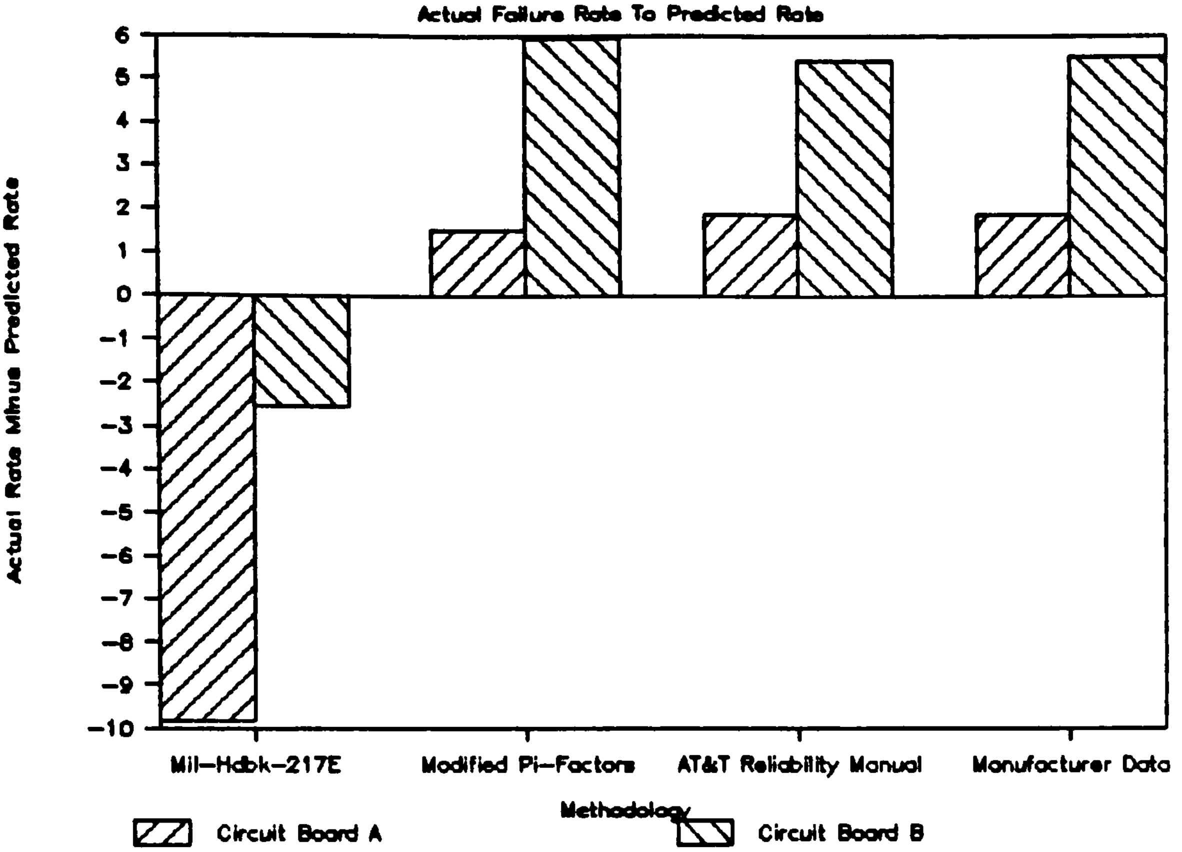
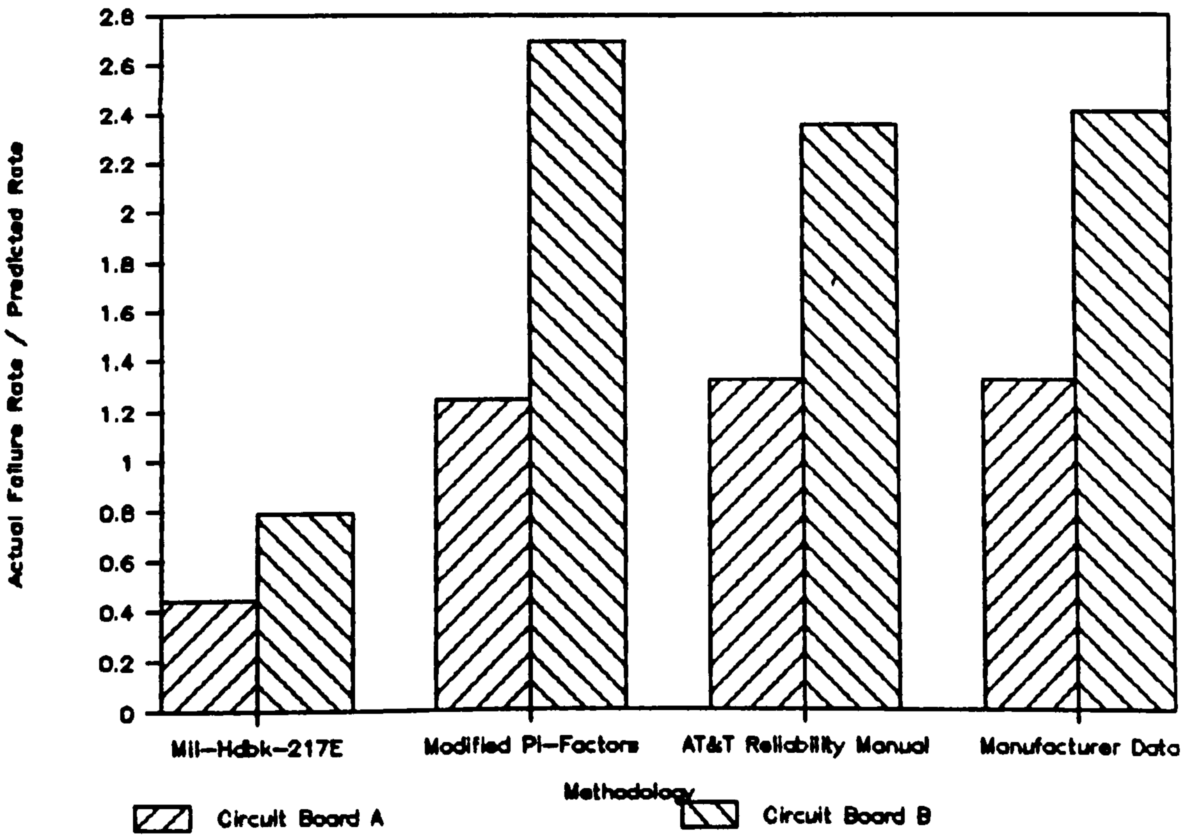


Figure 2, Correction Factors



The failure rates for Circuit Board A and Circuit Board B were calculated for the years 1989 and 1990. Failure rates for the circuit boards were predicted by Mil-Hdbk-217E, the Seidl and Garry Modified π-Factor Approach, The AT&T Reliability Manual, and a dynamic model using manufacturer data. These actual and predicted failure rates were compared; and a linear correction factor, K_x, was determined for each prediction technique.

IV. DISCUSSION

A. Circuit Board A:

Of the four methodologies employed in this study, three predicted essentially the same failure rate for Circuit Board A. These three, the Seidl and Garry Modified π-Factor Approach, The AT&T Reliability Manual, and the Dynamic Reliability Model called for between 5.9 and 6.3 failures per million hours of operation. These values are very close to the observed failure rate of 7.8 failures per million hours of operation, resulting in correction factors of between 1.2 and 1.3.

That the three predictors all came close to the actual failure rate and to each other reinforces their validity (that is, the process by which the reliability prediction was derived for each method yields results consistent with other established approaches). It is not unexpected that the methodologies' results were lower than the actual failure rate. Only the random failure rates of the components were calculated and summed to forecast the failure rate of the assembly. As mentioned earlier, non-component failures (environmental stresses, handling and assembly damage, etc.) are not included in the predictions. The proximity of the predictions and the observed data indicates that most of the failures of Circuit Board A are due to component failures and not to design defects, assembly defects, etc. In other words, a correction factor of about 1.3 implies that the design, manufacturing and environmental parameters experienced by Circuit Board A are not contributing substantially to the failure rate of the assembly.

The Mil-Hdbk-217E prediction overestimated the failure rate by a factor of about 2.3, which is consistent with the observations made by Blanks[5], Shen[10], and others. The pessimism of the Handbook's technique requires a correction factor far less than 1.0. By itself, such a correction factor is not an indication that the Handbook is unreliable in its predictive capability. However, a correction factor which is remote from the value of 1.0 carries a high sensitivity to its exact value. A small percentage change in a large or small correction factor is amplified into several more or fewer failures per million hours of operation. This sensitivity erodes the confidence of the prediction, and thus its value.

B. Circuit Board B:

The reliability predictions for Circuit Board B are strikingly similar to those of Circuit Board A. The Seidl and Garry Modified π-Factor Approach, The AT&T Reliability Manual, and the Dynamic Reliability Model all predict a failure rate within one half failure per million hours of operation of each other, roughly 3.9 failures. The Mil-Hdbk-217E prediction is much higher, at about 12 failures per million hours of operation. The ratio of the Mil-Hdbk-217E prediction to the average of the other three techniques for Circuit Board B is 3.1; similar to the value of 2.9 for Circuit Board A.

However, the comparison of the predicted values with the observed failure rate is very different from that seen on Circuit Board A. The Handbook provides the closest predicted failure rate, with the other three methods underestimating the observed rate by a factor of about 3.9. Either each of the four prediction techniques respond differently to Circuit Board B's inputs, many of which are the same as those in Circuit Board A, while maintaining their relative relationships; or the observed failure rate is being influenced by a factor unrelated to component failure. A further investigation into the events of 1989 and 1990 revealed that the latter is the case [28].

Since its integration into Circuit Board B, there has been a rising level of errors attributed to the A/D Converter, leading to a higher incidence of field replacement. Before being finally identified in 1990 as a design defect internal to the module, a large number of circuit boards had been installed in analyzers in the field. It is during this period that the data for this study was collected; data which included a much higher rate of field replacements of Circuit Board B. The error for the defect was reported and classified differently on Circuit Board A, which did not result in a higher replacement rate for that board. The artificially higher A/D Converter errors dominated the replacement rate of Circuit Board B during 1989 and 1990 and resulted in the disparity between the predicted failure rates and the observed failure rate. Consequently, the calculated correction factors for Circuit Board B includes the influence of a design defect, and is thus unusable in predicting the reliability of other circuit boards.

The experience with Circuit Board B dramatically illustrates one of the most important elements involved with reliability predictions. The prediction methodologies cannot account for design defects, manufacturing defects, or other events external to the model inputs. Unless the design of the assembly has excluded errors (race conditions, transients, etc.), production of the assembly is properly controlled, and the use of the device excludes extraordinary conditions, the component random failure rate will not dominate the replacement of the unit. Reliability prediction techniques deal only with those random failures, and cannot anticipate other events leading to field replacement. A predictor will quantify the component random failure rate; whereas the actual failure rate will be the sum of the component failure rate and any other factors leading to those failures. When another factor controls the performance of an assembly, a large difference between the predicted and actual failure rates is the inevitable consequence. Adequate control over design, manufacturing, assembly, and use, is a requirement before reliability prediction techniques can be useful.

C. Conclusions

Four reliability prediction techniques were applied to two circuit boards from an Ektachem Analyzer. The predicted failure rates were compared to the number of observed field replacements over a two-year period; and a linear correction factor was calculated for each methodology for each circuit board. From the analysis of the results, and subsequent investigations, the following can be concluded.

Mil-Hdbk-217E, as its predecessors, remains an extremely conservative predictor of reliability. In general, the Handbook overestimates the failure rate by a factor of about 2.

The Seidl and Garry, Modified π-Factor Approach, the AT&T Reliability Manual, and the Dynamic Reliability Model using Manufacturer's Data predicted the same failure rate for each circuit board. Any one of these three methods is a reasonable choice for use as a prediction technique.

A linear correction factor K_x, can be calculated and used for two purposes. One, the correction factor may be applied to the failure rate predictions of assembly designs not in production, and thus have no field history. The factor serves as a linear correction to the prediction technique employed specific to the user's design and assembly processes. Second, the correction factor can be recalculated once the field history of a device has been created, and compared to the value of the 'established' correction factor. A discrepancy between the two K_x values is representative of a process change; and can serve as an initiator of process control activities on the part of the manufacturer. The variation of observation with prediction can give illumination to a reliability problem, but not direction. Failure analysis techniques must be employed to determine which actions to take in the Reliability Improvement Process.

All reliability prediction techniques are utterly dependent upon a design and manufacturing process which avoids failure rate mechanisms external to the reliability model parameters which significantly affect the assembly failure rate relative to the random component failure rate. Design defects are unaccounted for in the prediction methodologies. Variations in incoming quality, inconsistent handling, and other circumstances will add error to the predictions generated. The resulting correction factor calculations will show a large difference between prediction and reality.

D. Further Studies Required

Only one circuit board, CBA, generated a useful average correction factor, which is, after all, this study's product. The next step to take is to choose one of the three more accurate reliability prediction methods, and apply the technique to a larger sample of circuit board designs. The resulting failure rate predictions, when compared to their respective field failure rates, will yield a new set of K_x values. If the correction factors are consistent, then the design and assembly process is controlled and repeatable; and the average of the aggregate K_x values may be used to correct predictions of assemblies yet to be built. Inconsistent K_x values indicate unwanted reliability variation and more investigative work ahead.

Circuit Board A, a well designed and built assembly, failed at close to the rate forecast by three of the four reliability prediction methodologies. The fourth, Mil-Hdbk-217E, overstated the actual failure rate by a factor of 2.3. Circuit Board B, a board containing a defect failed at a rate much higher than that predicted by the three methods which worked well on CBA. The disparity in prediction accuracy between the two boards signaled that Circuit Board B failed at a rate unexplained by random component failures. Good correlation between predicted and actual failure rates exists only when the design and production attributes of the manufacturer are and well controlled.

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Appendix A. Components of Circuit Boards A and B

Circuit Board A

INTEGRATED CIRCUITS
Both Versions of CBA

Name	Function	Type
LM339N	Quad Comparator	Bipolar
74LS154	Decoder	LSTTL
74LS32	Quad OR	LSTTL
74LS02	Quad NOR	LSTTL
74LS08	Quad AND	LSTTL
74LS139	Decoder	LSTTL
AD940	DC/DC Converter	Bipolar
74LS175	Quad D-FF Latch	LSTTL
74LS244	Octal Buffer	LSTTL
74LS244	Octal Buffer	LSTTL
74LS244	Octal Buffer	LSTTL
74LS244	Octal Buffer	LSTTL
74LS14	Hex Invertor (ST)	LSTTL
74LS245	Octal Bus Tranceiver	LSTTL
74LS373	Octal Latch	LSTTL
MP8018A	A/D Convertor	Hybrid
8255A-5	Intel PPI	NMOS
8259A	Intel PIC	NMOS
8253	Prog Intrv Tmr	HMOS
8085	CPU	HMOS
HM6116P-4	2K x 8 RAM	CMOS
HM6116P-4	2K x 8 RAM	CMOS
HM6264-LP15	8K x 8 RAM	CMOS
27C64-3	8K x 8 EPROM	CMOS
74LS04	Hex Invertor	TTL
UA78H05ASC	Voltage Regulator	Bipolar

Additional Components on Version 2 of CBA

Name	Function	Type
74LS373	Octal Latch	TTL
74LS244	Octal Buffer	TTL
7406	Hex Invertor	TTL
80C31	8 Bit uController	CMOS
74HC14	Hex Invertor	CMOS
MC3479P	Stepper Driver	Bipolar

Appendix A: Components of Circuit Board A

RESISTORS AND RESISTOR NETWORKS
Both Versions of CBA

Name	Function	Type
1 MegOhm	Resistor	Carbon
1 MegOhm	Resistor	Carbon
1 MegOhm	Resistor	Carbon
1 MegOhm	Resistor	Carbon
1 MegOhm	Resistor	Carbon
1 MegOhm	Resistor	Carbon
1 MegOhm	Resistor	Carbon
1 MegOhm	Resistor	Carbon
1 MegOhm	Resistor	Carbon
1 MegOhm	Resistor	Carbon
1 MegOhm	Resistor	Carbon
1 MegOhm	Resistor	Carbon
47 K Ohm	Resistor	Carbon
1 K Ohm	Resistor	Carbon Film
100 K Ohm	Resistor	Carbon Film
10 K Ohm	Resistor	Carbon Film
3 K Ohm	SIP Resistor Pack	
10 K Ohm	SIP Resistor Pack	
10 K Ohm	SIP Resistor Pack	

Additional Components on Version 2 of CBA

Name	Function	Type
20 K Ohm	Resistor	Carbon
1 MegOhm	Resistor	Carbon
150 K Ohm	Resistor	Carbon Film
22 K Ohm	Resistor	Carbon Film
82 Ohm	SIP Resistor Pack	
4.7 K Ohm	SIP Resistor Pack	
22 K Ohm	SIP Resistor Pack	
110 Ohm	SIP Resistor Pack	

Appendix A: Components of Circuit Board A
===

CAPACITORS

Both Versions of CBA

Name	Function	Type
====	========	====
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.1 uF	Capacitor	Ceramic
22 pF	Capacitor	Ceramic
1000 pF	Capacitor	Ceramic
1000 pF	Capacitor	Ceramic
1000 pF	Capacitor	Ceramic
47 uF	Capacitor	Electrolytic
1 uF	Capacitor	Electrolytic
10 uF	Capacitor	Electrolytic
10 uF	Capacitor	Electrolytic
10 uF	Capacitor	Electrolytic
100 uF	Capacitor	Electrolytic

Additional Components on Version 2 of CBA

Name	Function	Type
33 pF	Capacitor	Ceramic
33 pF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
10 uF	Capacitor	Electrolytic

Appendix A: Components of Circuit Board A

MISCELLANEOUS COMPONENTS, CONNECTORS, SOCKETS
Both Versions of CBA

Name	Function	Type
2N4401	Transistor	NPN
1N5817	Diode	Bipolar
1N5817	Diode	Bipolar
1N5817	Diode	Bipolar
555-2007	Indicator LED	
555-2007	Indicator LED	
555-2007	Indicator LED	
555-2007	Indicator LED	
105-0751-001	Test Point	
105-0751-001	Test Point	
105-0751-001	Test Point	
105-0751-003	Test Point	
105-0751-003	Test Point	
105-0751-003	Test Point	
105-0751-003	Test Point	
105-0751-003	Test Point	
105-0751-003	Test Point	
105-0751-003	Test Point	
105-0751-003	Test Point	
105-0751-003	Test Point	
105-0751-003	Test Point	
4 MHz	Crystal	
87578-5	16 Pin Connector	
207541-1	3 Pin Connector	
609-5014E	50 Pin Connector	
3-87516-5	6 Pin Connector	
1-87227-3	26 Pin Connector	
1-87227-3	26 Pin Connector	
ES-7459-01-01	5 Socket Pins	

Appendix A: Components of Circuit Board A

MISCELLANEOUS COMPONENTS, CONNECTORS, SOCKETS
Both Versions of CBA

Name	Function	Type
814-AG11D	14 Pin Socket	
814-AG11D	14 Pin Socket	
814-AG11D	14 Pin Socket	
814-AG11D	14 Pin Socket	
814-AG11D	14 Pin Socket	
814-AG11D	14 Pin Socket	
814-AG11D	14 Pin Socket	
816-AG11D	16 Pin Socket	
816-AG11D	16 Pin Socket	
820-AG11D	20 Pin Socket	
820-AG11D	20 Pin Socket	
820-AG11D	20 Pin Socket	
820-AG11D	20 Pin Socket	
820-AG11D	20 Pin Socket	
820-AG11D	20 Pin Socket	
820-AG11D	20 Pin Socket	
824-AG11D	24 Pin Socket	
824-AG11D	24 Pin Socket	
824-AG11D	24 Pin Socket	
824-AG11D	24 Pin Socket	
828-AG11D	28 Pin Socket	
828-AG11D	28 Pin Socket	
828-AG11D	28 Pin Socket	
840-AG11D	40 Pin Socket	
840-AG11D	40 Pin Socket	
814-AG11D	14 Pin Socket	
814-AG11D	14 Pin Socket	
820-AG11D	20 Pin Socket	
824-AG11D	24 Pin Socket	
824-AG11D	24 Pin Socket	
828-AG11D	28 Pin Socket	
828-AG11D	28 Pin Socket	
828-AG11D	28 Pin Socket	
828-AG11D	28 Pin Socket	
840-AG11D	40 Pin Socket	
Bare Printed Circuit Board		
Amp 87578-7	20 Pin Connector	

Additional Components on Version 2 of CBA

Name	Function	Type
12 MHz	Crystal	
HM6264-LP15	RAM	
840-AG11D	4 Sockets	
828-AG11D	3 Sockets	

Appendix A: Components of Circuit Boards A and B,
A/D Convertor

INTEGRATED CIRCUITS

Name	Function	Type
LF411	Op Amp	Bipolar
OP27GP	Op Amp	Bipolar
OP27GP	Op Amp	Bipolar
LM301A	Op Amp	Bipolar
LM319	Dual Comparator	Bipolar
74LS04	Hex Invertor	LSTTL
74LS08	Quad AND	LSTTL
74LS51	Dual AND-OR	LSTTL
74LS74	Dual D-Flip Flop	LSTTL
74LS74	Dual D-Flip Flop	LSTTL
74LS74	Dual D-Flip Flop	LSTTL
74LS138	3 to 8 Decoder	LSTTL
74LS151	Multiplexer	LSTTL
74LS161	Counter	LSTTL
74LS161	Counter	LSTTL
74LS164	Shift Register	LSTTL
74LS169	Counter	LSTTL
74LS175	Quad D-Flip Flop	LSTTL
74LS374	Octal Latch	LSTTL
74LS590	Counter	LSTTL
74LS697	Counter	LSTTL
74LS697	Counter	LSTTL
HI201	Quad Switch	CMOS
HI201	Quad Switch	CMOS
74HCT4040	Counter	CMOS
ICM7209	Clock Generator	CMOS

Appendix A: Components of CBA and CBB, A/D Convertor
RESISTORS & RESISTOR NETWORKS

====	========	====
10 Ohm	Resistor	Metal Film
100 Ohm	Resistor	Metal Film
100 Ohm	Resistor	Metal Film
1 K Ohm	Resistor	Metal Film
10 K Ohm	Resistor	Metal Film
13 K Ohm	Resistor	Metal Film
0 Ohm	Resistor	Metal Film
0 Ohm	Resistor	Metal Film
2 K Ohm	Resistor	Metal Film
20 K Ohm	Resistor	Metal Film
220 Ohm	Resistor	Metal Film
270 Ohm	Resistor	Metal Film
27 K Ohm	Resistor	Metal Film
3.3 K Ohm	Resistor	Metal Film
3.6 K Ohm	Resistor	Metal Film
390 Ohm	Resistor	Metal Film
3.9 K Ohm	Resistor	Metal Film
47 K Ohm	Resistor	Metal Film
510 Ohm	Resistor	Metal Film
5.1 K Ohm	Resistor	Metal Film
56 K Ohm	Resistor	Metal Film
6.8 K Ohm	Resistor	Metal Film
6.8 K Ohm	Resistor	Metal Film
680 K Ohm	Resistor	Metal Film
5.1 K Ohm	Resistor	Metal Film
100 Ohm	Resistor	Metal Film
12.4 K Ohm	Resistor	Metal Film
12.4 K Ohm	Resistor	Metal Film
124 K Ohm	Resistor	Metal Film
15 K Ohm	Resistor	Metal Film
15 K Ohm	Resistor	Metal Film
2.37 K Ohm	Resistor	Metal Film
2.37 K Ohm	Resistor	Metal Film
4.87 K Ohm	Resistor	Metal Film
47.5 K Ohm	Resistor	Metal Film
4.99 K Ohm	Resistor	Metal Film
4.99 K Ohm	Resistor	Metal Film
4.99 K Ohm	Resistor	Metal Film
4.99 K Ohm	Resistor	Metal Film
6.65 K Ohm	Resistor	Metal Film
6.65 K Ohm	Resistor	Metal Film
182 Ohm	Resistor	Metal Film
7.5 K Ohm	Resistor	Metal Film
121 K Ohm	Resistor	Metal Film
1.5 k Ohm	Resistor	Metal Film
499 Ohm	Resistor	Metal Film
499 Ohm	Resistor	Metal Film
20 Ohm	Potentiometer	
5.1 K Ohm	Resistor SIP	

Appendix A: Components of CBA and CBB, A/D Convertor

CAPACITORS

Name	Function	Type
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
0.01 uF	Capacitor	Ceramic
18 pF	Capacitor	Ceramic
18 pF	Capacitor	Ceramic
18 pF	Capacitor	Ceramic
100 pF	Capacitor	Ceramic
100 pF	Capacitor	Ceramic
220 pF	Capacitor	Ceramic
220 pF	Capacitor	Ceramic
220 pF	Capacitor	Ceramic
470 pF	Capacitor	Ceramic
680 pF	Capacitor	Ceramic
680 pF	Capacitor	Ceramic
0.1 uF	Capacitor	Ceramic
0.1 uF	Capacitor	Ceramic
0.1 uF	Capacitor	Ceramic
0.1 uF	Capacitor	Ceramic
4.7 uF	Capacitor	Tantalum
4.7 uF	Capacitor	Tantalum
4.7 uF	Capacitor	Tantalum
4.7 uF	Capacitor	Tantalum
4.7 uF	Capacitor	Tantalum
4.7 uF	Capacitor	Tantalum
6.8 uF	Capacitor	Tantalum
0.1 uF	Capacitor	Polypropylene

Appendix A: Components of Circuit Boards A and B,
A/D Convertor

MISCELLANEOUS COMPONENTS, CONNECTORS, SOCKETS

Name	Function	Type
SD211	Quad Switch	CMOS
SD211	Quad Switch	CMOS
IMF6485	Dual Amp	JFET
2N3906	PNP Transistor	Silicon
2N3906	PNP Transistor	Silicon
2N3904	NPN Transistor	Silicon
FDH300	Diode	Bipolar
FDH300	Diode	Bipolar
FDH300	Diode	Bipolar
FDH300	Diode	Bipolar
FDH300	Diode	Bipolar
1N4148	Diode	Bipolar
1N4148	Diode	Bipolar
1N4148	Diode	Bipolar
1N4148	Diode	Bipolar
1N6263	Diode	Bipolar
1N6263	Diode	Bipolar
1N6263	Diode	Bipolar
1N6263	Diode	Bipolar
1N702A	Diode	Bipolar
6.35V Ref	Diode	Bipolar
2.4576 MHz	Crystal	
1-86418-7	26 Pin Connector	
1-86418-7	26 Pin Connector	
Bare Printed Circuit Board		

Appendix A: Components of Circuit Board B

INTEGRATED CIRCUITS

Name	Function	Type
MC6802	Microprocessor	HMOS
74LS32	Quad OR	LSTTL
74LS244	Octal Buffer	LSTTL
74LS244	Octal Buffer	LSTTL
74LS244	Octal Buffer	LSTTL
74LS240	Octal Invertor/Drvr	LSTTL
74LS240	Octal Invertor/Drvr	LSTTL
MC6821	PIA	NMOS
74LS139	Decoder	LSTTL
HM6264-LP15	8K x 8 RAM	CMOS
LM339N	Quad Comparator	Bipolar
74HCT374	Octal Latch	CMOS
PMI OP-07EJ	Op-Amp	Bipolar
74LS138	Decoder	LSTTL
AD940	DC/DC Convertor	Bipolar
MP298	PGA	
MP8018A	A/D Convertor	

RESISTORS

Name	Function	Type
20 K Ohm	Resistor	Metal Film
20 K Ohm	Resistor	Metal Film
10 K Ohm	Resistor	Metal Film
10 K Ohm	Resistor	Metal Film
10 K Ohm	Resistor	Metal Film
3.3 K Ohm	Resistor	Carbon Film
3.3 K Ohm	Resistor	Carbon Film
3.3 K Ohm	Resistor	Carbon Film
3.3 K Ohm	Resistor	Carbon Film
3.3 K Ohm	Resistor	Carbon Film
3.3 K Ohm	Resistqr	Carbon Film
100 Ohms	Resistor	Carbon Film
100 Ohms	Resistor	Carbon Film
100 Ohms	Resistor	Carbon Film
100 Ohms	Resistor	Carbon Film
100 Ohms	Resistor	Carbon Film
100 Ohms	Resistor	Carbon Film
100 Ohms	Resistor	Carbon Film
100 Ohms	Resistor	Carbon Film
82 Ohms	Resistor	Carbon Film
82 Ohms	Resistor	Carbon Film
82 Ohms	Resistor	Carbon Film
82 Ohms	Resistor	Carbon Film

Appendix A: Components of Circuit Board B

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RESISTORS

Name	Function	Type
====	========	====
10 K Ohms	Resistor	Carbon Film
10 K Ohms	Resistor	Carbon Film
10 K Ohms	Resistor	Carbon Film
10 K Ohms	Resistor	Carbon Film
10 K Ohms	Resistor	Carbon Film
10 K Ohms	Resistor	Carbon Film
10 K Ohms	Resistor	Carbon Film
10 K Ohms	Resistor	Carbon Film
10 K Ohms	Resistor	Carbon Film
10 K Ohms	Resistor	Carbon Film
20 K Ohms	Resistor	Carbon Film
20 K Ohms	Resistor	Carbon Film
20 K Ohms	Resistor	Carbon Film
20 K Ohms	Resistor	Carbon Film
1 MegOhm	Resistor	Carbon Film
1 MegOhm	Resistor	Carbon Film
1 MegOhm	Resistor	Carbon Film
1 MegOhm	Resistor	Carbon Film
1 MegOhm	Resistor	Carbon Film
1 MegOhm	Resistor	Carbon Film
1 MegOhm	Resistor	Carbon Film
1 MegOhm	Resistor	Carbon Film
1 MegOhm	Resistor	Carbon Film
1 MegOhm	Resistor	Carbon Film
1 MegOhm	Resistor	Carbon Film
1 MegOhm	Resistor	Carbon Film

Appendix A: Components of Circuit Board B
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CAPACITORS

Name	Function	Type
====	========	====
10 uF, 100V	Capacitor	Electrolytic
10 uF, 100V	Capacitor	Electrolytic
10 uF, 100V	Capacitor	Electrolytic
27 pF, 50 V	Capacitor	Ceramic
27 pF, 50 V	Capacitor	Ceramic
.01 uF, 50 V	Capacitor	Ceramic
.01 uF, 50 V	Capacitor	Ceramic
.01 uF, 50 V	Capacitor	Ceramic
.01 uF, 50 V	Capacitor	Ceramic
.01 uF, 50 V	Capacitor	Ceramic
.01 uF, 50 V	Capacitor	Ceramic
.01 uF, 50 V	Capacitor	Ceramic
.01 uF, 50 V	Capacitor	Ceramic
.01 uF, 50 V	Capacitor	Ceramic
.01 uF, 50 V	Capacitor	Ceramic
.01 uF, 50 V	Capacitor	Ceramic
.01 uF, 50 V	Capacitor	Ceramic
.01 uF, 50 V	Capacitor	Ceramic
.01 uF, 50 V	Capacitor	Ceramic
.01 uF, 50 V	Capacitor	Ceramic
.01 uF, 50 V	Capacitor	Ceramic
.01 uF, 50 V	Capacitor	Ceramic
.01 uF, 50 V	Capacitor	Ceramic
.01 uF, 50 V	Capacitor	Ceramic
.01 uF, 50 V	Capacitor	Ceramic
.01 uF, 50 V	Capacitor	Ceramic
.01 uF, 50 V	Capacitor	Ceramic
.01 uF, 50 V	Capacitor	Ceramic
47 uF, 50 V	Capacitor	Ceramic
0.1 uF, 50 V	Capacitor	Ceramic
0.1 uF, 50 V	Capacitor	Ceramic

Appendix A: Components of Circuit Board B

MISCELLANEOUS COMPONENTS, CONNECTORS, SOCKETS

Name	Function	Type
4 MHz	Crystal	
3-87516-5	6 Pin Connector	
"	6 Pin Connector	
"	6 Pin Connector	
"	6 Pin Connector	
"	6 Pin Connector	
3M 3432-1302	40 Pin Connector	
AMP 1-86418-7	26 Pin Connector	
"	26 Pin Connector	
AMP 1-87215-1	4 Pin Connector	
AMP 87215-5	16 Pin Connector	
814-AG11D	14 Pin Socket	
	20 Pin Socket	
	20 Pin Socket	
	20 Pin Socket	
	20 Pin Socket	
	20 Pin Socket	
	20 Pin Socket	
828-AG11D	28 Pin Socket	
828-AG11D	28 Pin Socket	
840-AG11D	40 Pin Socket	
840-AG11D	40 Pin Socket	
TO-3	2 Pin Socket	

Bare Printed Circuit Board

Appendix A: Components of Circuit Board B, Programmable Gain Amplifier

INTEGRATED CIRCUITS

Name	Function	Type
4052B	Multiplexer	CMOS
LF 412 CN	Op Amp	Bipolar
DAC-08E	D/A Convertor	Bipolar
AM25L03PC	Suc. App. Reg.	TTL
74HCT273	Oct D Flip-Flop	CMOS
4053B	Triple 2 Ch Mux	CMOS
4093B	Schmitt Trigger	CMOS
LM308A	Op Amp	Bipolar
4051B	8 Ch Analog Mux	CMOS

RESISTORS

Name	Function	Type
1 K Ohm	Resistor	Metal Film
1 K Ohm	Resistor	Metal Film
1 K Ohm	Resistor	Metal Film
1 K Ohm	Resistor	Metal Film
100 K Ohm	Resistor	Metal Film
100 K Ohm	Resistor	Metal Film
100 K Ohm	Resistor	Metal Film
100 K Ohm	Resistor	Metal Film
100 K Ohm	Resistor	Metal Film
100 K Ohm	Resistor	Metal Film
100 K Ohm	Resistor	Metal Film
100 K Ohm	Resistor	Metal Film
100 K Ohm	Resistor	Metal Film
10 K Ohm	Resistor	Metal Film
10 K Ohm	Resistor	Metal Film
10 K Ohm	Resistor	Metal Film
10 K Ohm	Resistor	Metal Film
10 K Ohm	Resistor	Metal Film
10 K Ohm	Resistor	Metal Film
10 K Ohm	Resistor	Metal Film
10 K Ohm	Resistor	Metal Film
240 K Ohm	Resistor	Metal Film
5.1 K Ohm	Resistor	Metal Film
5.1 K Ohm	Resistor	Metal Film
5.1 K Ohm	Resistor	Metal Film
330 K Ohm	Resistor	Metal Film
330 K Ohm	Resistor	Metal Film
2.7 K Ohm	Resistor	Metal Film
2.7 K Ohm	Resistor	Metal Film

Appendix A: Components of Circuit Board B, Programmable Gain Amplifier

RESISTORS

Name	Function	Type
680 Ohm	Resistor	Metal Film
680 Ohm	Resistor	Metal Film
750 Ohm	Resistor	Metal Film
2.4 K Ohm	Resistor	Metal Film
3.0 K Ohm	Resistor	Metal Film
1 M Ohm	Resistor	Metal Film
33 Ohm	Resistor	Metal Film
62 K Ohm	Resistor	Metal Film
62 K Ohm	Resistor	Metal Film
3.92 K Ohm	Resistor	Metal Film
42.2 K Ohm	Resistor	Metal Film
499 Ohm	Resistor	Metal Film
4.87 K Ohm	Resistor	Metal Film
4.99 K Ohm	Resistor	Metal Film
1 M Ohm	Resistor	Metal Film
1 M Ohm	Resistor	Metal Film
1 M Ohm	Resistor	Metal Film
2 K Ohm	Resistor	Metal Film
10 Pin	Resistor SIP	
8 Pin	Resistor SIP	

CAPACITORS

Name	Function	Type
.01 uF, 50V	Capacitor	Ceramic
0.022 uF	Capacitor	Ceramic
15 pF, 50V	Capacitor	Ceramic
0.1 uF	Capacitor	Ceramic
1000 pF	Capacitor	Ceramic
1000 pF	Capacitor	Ceramic
1000 pF	Capacitor	Ceramic
0.1 Uf	Capicator	Polycarbonate
6.8 uF	Capacitor	Tantalum
6.8 uF	Capacitor	Tantalum
6.8 uF	Capacitor	Tantalum

Appendix A: Components of Circuit Board B, Programmable Gain Amplifier

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MISCELLANEOUS COMPONENTS

Name	Function	Type
2N3906	PNP Transistor	Silicon
2N3906	PNP Transistor	Silicon
2N3906	PNP Transistor	Silicon
2N3906	PNP Transistor	Silicon
2N3906	PNP Transistor	Silicon
2N3906	PNP Transistor	Silicon
2N3906	PNP Transistor	Silicon
2N3906	PNP Transistor	Silicon
2N3904	NPN Transistor	Silicon
2N3904	NPN Transistor	Silicon
2N3904	NPN Transistor	Silicon
J177	P Channel JFET	Silicon
FDH300	Diode	Bipolar
FDH300	Diode	Bipolar
1N4148	Diode	Bipolar
1N6263	Diode	Bipolar
1N6263	Diode	Bipolar
1N753A	Zener Diode	Bipolar
1N758A	Zener Diode	Bipolar
1N746A	Zener Diode	Bipolar
1N961B	Zener Diode	Bipolar
1N961B	Zener Diode	Bipolar
1N961B	Zener Diode	Bipolar
1N961B	Zener Diode	Bipolar
	24 Socket Pins	

Bare Printed Circuit Board

APPENDIX B
Circuit Board A: MIL-HDBK-217E Reliability Prediction

INTEGRATED CIRCUITS (Both Versions of CBA)

Name	Function	Type	Failure Rate	# of Pins	Pi Q	C1	Pi T: Pt	X	A	Tj	T
LM339N	Quad Comparator	Bipolar	0.178	14	20	0.01	0.698	1.943	10429	42.519	3
74LS154	Decoder	LSTTL	0.124	24	20	0.01	0.241	0.881	6373	37.800	3
74LS32	Quad OR	LSTTL	0.085	14	20	0.01	0.229	0.828	6373	37.000	3
74LS02	Quad NOR	LSTTL	0.082	14	20	0.01	0.215	0.766	6373	36.075	3
74LS08	Quad AND	LSTTL	0.084	14	20	0.01	0.224	0.808	6373	36.700	3
74LS139	Decoder	LSTTL	0.094	16	20	0.01	0.240	0.877	6373	37.750	3
AD940	DC/DC Convertor	Bipolar	1.440	5	20	0.01	2.099	3.044	10429	53.390	3
74LS175	Quad D-FF Latch	LSTTL	0.100	16	20	0.01	0.270	0.992	6373	39.500	3
74LS244	Octal Buffer	LSTTL	0.125	20	20	0.01	0.323	1.173	6373	42.300	3
74LS244	Octal Buffer	LSTTL	0.125	20	20	0.01	0.323	1.173	6373	42.300	3
74LS244	Octal Buffer	LSTTL	0.125	20	20	0.01	0.323	1.173	6373	42.300	3
74LS244	Octal Buffer	LSTTL	0.125	20	20	0.01	0.323	1.173	6373	42.300	3
74LS14	Hex Invertor (ST)	LSTTL	0.093	14	20	0.01	0.272	1.000	6373	39.625	3
74LS245	Octal Bus Tranceiver	LSTTL	0.179	20	20	0.01	0.591	1.777	6373	52.000	3
74LS373	Octal Latch	LSTTL	0.128	20	20	0.01	0.338	1.218	6373	43.000	3
MP8018A	A/D Convertor	Hybrid	5.111	36							
8255A-5	Intel PPI	NMOS	0.577	40	20	0.03	0.822	2.107	8111	50.000	3
8259A	Intel PIC	NMOS	0.624	28	20	0.03	0.888	2.184	8111	51.000	3
8253	Prog Intrv Tmr	HMOS	1.179	24	20	0.03	2.172	3.078	8111	63.000	3
8085	CPU	HMOS	0.715	40	20	0.03	0.950	2.252	8111	51.875	3
HM6116P-4	2K x 8 RAM	CMOS	0.584	24	20	0.025	1.016	2.319	9270	49.000	3
HM6116P-4	2K x 8 RAM	CMOS	0.584	24	20	0.025	1.016	2.319	9270	49.000	3
HM6264-LP15	8K x 8 RAM	CMOS	0.736	28	20	0.05	0.645	1.064	9270	44.000	3
27C64-3	8K x 8 EPROM	CMOS	0.495	28	20	0.05	0.404	1.396	9270	39.000	3
74LS04	Hex Invertor	TTL	0.093	14	20	0.01	0.272	1.000	6373	39.625	3
UA78H05ASC	Voltage Regulator	Bipolar	1.827	[illegible]	20	0.01	9.125	4.514	10429	69.125	3

Version 2 Only Components

Name	Function	Type	Failure Rate	# of Pins	Pi Q	C1	Pi T: Pt	X	A	Tj	T
74LS373	Octal Latch	TTL	0.128	20	20	0.01	0.338	1.218	6373	43.000	3
74LS244	Octal Buffer	TTL	0.125	20	20	0.01	0.323	1.173	6373	42.300	3
7406	Hex Invertor	TTL	0.087	14	20	0.01	0.239	0.872	5214	40.625	3
80C31	8 Bit uController	CMOS	0.564	40	20	0.06	0.350	1.252	9270	37.500	3
74HC14	Hex Invertor	CMOS	0.151	14	20	0.01	0.562	1.725	9270	42.500	3
MC3479P	Stepper Driver	Bipolar	0.347	16	20	0.01	1.5	2.709	10429	50.000	3

Integrated Circuits Failure Rate 15.816 Version 1
16.482 Version 2

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thjc	P	Pi V	C2	Pi E	Pi L
50	0.150	1	0.0051	0.38	1
40	0.070	1	0.01	0.38	1
50	0.040	1	0.0051	0.38	1
50	0.022	1	0.0051	0.38	1
50	0.034	1	0.0051	0.38	1
50	0.055	1	0.0061	0.38	1
10	1.839	1	0.00145	0.38	1
50	0.090	1	0.0061	0.38	1
40	0.183	1	0.008	0.38	1
40	0.183	1	0.008	0.38	1
40	0.183	1	0.008	0.38	1
40	0.183	1	0.008	0.38	1
50	0.093	1	0.0051	0.38	1
40	0.425	1	0.008	0.38	1
40	0.200	1	0.008	0.38	1
				0.38	1
25	0.600	1	0.011	0.38	1
40	0.400	1	0.012	0.38	1
40	0.700	1	0.01	0.38	1
25	0.675	1	0.019	0.38	1
40	0.350	1	0.01	0.38	1
40	0.350	1	0.01	0.38	1
40	0.225	1	0.012	0.38	1
40	0.100	1	0.012	0.38	1
50	0.093	1	0.0051	0.38	1
5	6.825	1	0.0003	0.38	1

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thjc	P	Pi V	C2	Pi E	Pi L
40	0.200	1	0.008	0.38	1
40	0.183	1	0.008	0.38	1
50	0.113	1	0.0051	0.38	1
25	0.100	1	0.019	0.38	1
50	0.150	1	0.0051	0.38	1
50	0.300	1	0.0061	0.38	1

Circuit Board A: MIL-HDBK-217E Reliability Prediction

RESISTORS & RESISTOR NETWORKS (Both Versions of CBA)

Name	Function	Type	Failure Rate	Lb	A	B	T	Nt	G	S
1 MegOhm	Resistor	Carbon	0.011	0.000657	4.50E-09	12	35	343	1	0.0001
1 MegOhm	Resistor	Carbon	0.011	0.000657	4.50E-09	12	35	343	1	0.0001
1 MegOhm	Resistor	Carbon	0.011	0.000657	4.50E-09	12	35	343	1	0.0001
1 MegOhm	Resistor	Carbon	0.011	0.000657	4.50E-09	12	35	343	1	0.0001
1 MegOhm	Resistor	Carbon	0.011	0.000657	4.50E-09	12	35	343	1	0.0001
1 MegOhm	Resistor	Carbon	0.011	0.000657	4.50E-09	12	35	343	1	0.0001
1 MegOhm	Resistor	Carbon	0.011	0.000657	4.50E-09	12	35	343	1	0.0001
1 MegOhm	Resistor	Carbon	0.011	0.000657	4.50E-09	12	35	343	1	0.0001
1 MegOhm	Resistor	Carbon	0.011	0.000657	4.50E-09	12	35	343	1	0.0001
1 MegOhm	Resistor	Carbon	0.011	0.000657	4.50E-09	12	35	343	1	0.0001
1 MegOhm	Resistor	Carbon	0.011	0.000657	4.50E-09	12	35	343	1	0.0001
1 MegOhm	Resistor	Carbon	0.011	0.000657	4.50E-09	12	35	343	1	0.0001
47 K Ohm	Resistor	Carbon	0.011	0.000660	4.50E-09	12	35	343	1	0.002
1 K Ohm	Resistor	Carbon Film	0.010	0.000639	3.25E-04	1	35	343	3	0.0000
100 K Ohm	Resistor	Carbon Film	0.010	0.000640	3.25E-04	1	35	343	3	0.001

Name	Function	Failure Rate		Lb	Nr	Pi T	Pi E	Pi Q
3 K SIP	Resistor Pack	0.012	10	0.00066	4	1.56	1	3
10 K SIP	Resistor Pack	0.022	10	0.00066	7	1.56	1	3
10 K SIP	Resistor Pack	0.025		0.00066	8	1.56	1	3

Version 2 Only Components

Name	Function	Type	Failure Rate	Lb	A	B	T	Nt	G	S
20 K Ohm	Resistor	Carbon	0.011	0.000670	4.50E-09	12	35	343	1	0.01
1 MegOhm	Resistor	Carbon	0.011	0.000657	4.50E-09	12	35	343	1	0.0001
150 K Ohm	Resistor	Carbon Film	0.010	0.000640	3.25E-04	1	35	343	3	0.0006
22 K Ohm	Resistor	Carbon Film	0.010	0.000641	3.25E-04	1	35	343	3	0.003

Name	Function	Failure Rate		Lb	Nr	Pi T	Pi E	Pi Q
82 Ohm	Resistor SIP	0.012	6	0.00066	4	1.56	1	3
4.7 K Ohm	SIP Resistor	0.012	6	0.00066	4	1.56	1	3
22 K Ohm	Resistor Pack	0.009	6	0.00066	3	1.56	1	3
110 Ohm	Resistor Pack	0.012	6	0.00066	4	1.56	1	3

Resistors Failure Rate 0.219 Version 1

0.306 Version 2

Ns	J	H	Pi E	Pi R	Pi Q
0.6	1	1	1	1.1	15
0.6	1	1	1	1.1	15
0.6	1	1	1	1.1	15
0.6	1	1	1	1.1	15
0.6	1	1	1	1.1	15
0.6	1	1	1	1.1	15
0.6	1	1	1	1.1	15
0.6	1	1	1	1.1	15
0.6	1	1	1	1.1	15
0.6	1	1	1	1.1	15
0.6	1	1	1	1.1	15
0.6	1	1	1	1.1	15
0.6	1	1	1	1.1	15
1	1	1	1	1	15
1	1	1	1	1	15

0.6	1	1	1	1.1	15
0.6	1	1	1	1.1	15
1	1	1	1	1	15
1	1	1	1	1	15

Circuit Board A: MIL-HDBK-217E Reliability Prediction

CAPACITORS (Both Versions of CBA)

Name	Function	Type	Failure Rate	Lb	Pe E	Pi Q	Pi CV
0.01 uF	Capacitor	Ceramic	0.0084	0.00074	1	10	1.1292
0.01 uF	Capacitor	Ceramic	0.0084	0.00074	1	10	1.1292
0.01 uF	Capacitor	Ceramic	0.0084	0.00074	1	10	1.1292
0.01 uF	Capacitor	Ceramic	0.0084	0.00074	1	10	1.1292
0.01 uF	Capacitor	Ceramic	0.0084	0.00074	1	10	1.1292
0.01 uF	Capacitor	Ceramic	0.0084	0.00074	1	10	1.1292
0.01 uF	Capacitor	Ceramic	0.0095	0.00084	1	10	1.1292
0.01 uF	Capacitor	Ceramic	0.0084	0.00074	1	10	1.1292
0.01 uF	Capacitor	Ceramic	0.0095	0.00084	1	10	1.1292
0.01 uF	Capacitor	Ceramic	0.0084	0.00074	1	10	1.1292
0.01 uF	Capacitor	Ceramic	0.0084	0.00074	1	10	1.1292
0.01 uF	Capacitor	Ceramic	0.0084	0.00074	1	10	1.1292
0.01 uF	Capacitor	Ceramic	0.0084	0.00074	1	10	1.1292
0.01 uF	Capacitor	Ceramic	0.0084	0.00074	1	10	1.1292
0.01 uF	Capacitor	Ceramic	0.0084	0.00074	1	10	1.1292
0.01 uF	Capacitor	Ceramic	0.0084	0.00074	1	10	1.1292
0.01 uF	Capacitor	Ceramic	0.0084	0.00074	1	10	1.1292
0.01 uF	Capacitor	Ceramic	0.0084	0.00074	1	10	1.1292
0.01 uF	Capacitor	Ceramic	0.0084	0.00074	1	10	1.1292
0.01 uF	Capacitor	Ceramic	0.0084	0.00074	1	10	1.1292
0.01 uF	Capacitor	Ceramic	0.0084	0.00074	1	10	1.1292
0.01 uF	Capacitor	Ceramic	0.0084	0.00074	1	10	1.1292
0.01 uF	Capacitor	Ceramic	0.0084	0.00074	1	10	1.1292
0.01 uF	Capacitor	Ceramic	0.0084	0.00074	1	10	1.1292
0.01 uF	Capacitor	Ceramic	0.0084	0.00074	1	10	1.1292
0.1 uF	Capacitor	Ceramic	0.0946	0.0065	1	10	1.4547
22 pF	Capacitor	Ceramic	0.0039	0.00068	1	10	0.5760
1000 pF	Capacitor	Ceramic	0.0060	0.00068	1	10	0.8765
1000 pF	Capacitor	Ceramic	0.0060	0.00068	1	10	0.8765
1000 pF	Capacitor	Ceramic	0.0060	0.00068	1	10	0.8765
47 uF	Capacitor	Electrolytic	0.0816	0.012	1	10	0.6799
1 uF	Capacitor	Electrolytic	0.0576	0.018	1	10	0.[illegible]2
10 uF	Capacitor	Electrolytic	0.0892	0.018	1	10	0.4956
10 uF	Capacitor	Electrolytic	0.0917	0.0185	1	10	0.4956
10 uF	Capacitor	Electrolytic	0.0917	0.0185	1	10	0.4956
100 uF	Capacitor	Electrolytic	0.1267	0.0165	1	10	0.7676

Circuit Board A: MIL-HDBK-217E Reliability Prediction

CAPACITORS (Version 2 Only Components)

Name	Function	Type	Failure Rate	Lb	Pe E	Pi Q	Pi CV
33 pF	Capacitor	Ceramic	0.0041	0.00068	1	10	0.6023
33 pF	Capacitor	Ceramic	0.0041	0.00068	1	10	0.6023
0.01 uF	Capacitor	Ceramic	0.0084	0.00074	1	10	1.1292
0.01 uF	Capacitor	Ceramic	0.0084	0.00074	1	10	1.1292
0.01 uF	Capacitor	Ceramic	0.0084	0.00074	1	10	1.1292
0.01 uF	Capacitor	Ceramic	0.0084	0.00074	1	10	1.1292
0.01 uF	Capacitor	Ceramic	0.0084	0.00074	1	10	1.1292
10 uF	Capacitor	Electrolytic	0.0892	0.018	1	10	0.4956

Capacitors Failure Rate 0.866 Version 1
1.005 Version 2

Circuit Board A: MIL-HDBK-217E Reliability Prediction

MISCELLANEOUS COMPONENTS, CONNECTORS, SOCKETS (Both Versions of CBA)

Name	Function	Type	Failure Rate	Lb	A	Nt	Tm	P	DT	S
2N4401	NPN Transistor		0.0069	0.000634	0.0189	-1052	448	10.5	150	0.0012

Name	Function	Failure Rate	Lb	Pi E	Pi Q	Pi R	Pi A	Pi S2	Pi C
1N5817	Diode	0.005	0.00045	1	15	1	1.000	0.700	1
1N5817	Diode	0.005	0.00045	1	15	1	1.000	0.700	1
1N5817	Diode	0.008	0.00075	1	15	1	1.000	0.700	1

Name	Function	Failure Rate	Lb	Pi E	Pi Q
4 MHz	Crystal	0.038	0.017882	1	2.1

Name	Function	Failure Rate	Lb	A	X	Nt	T	To	P	Pi E
87578-5	16 Pin Connector	0.001	0.000323	0.216	-6.504	-2073.6	35.0	423	4.66	1
207541-1	3 Pin Connector	0.001	0.000348	0.216	-6.429	-2073.6	30.0	423	4.66	1
609-5014E	50 Pin Connector	0.003	0.000323	0.216	-6.504	-2073.6	35.0	423	4.66	1
3-87516-5	6 Pin Connector	0.001	0.000323	0.216	-6.504	-2073.6	35.0	423	4.66	1
1-87227-3	26 Pin Connector	0.002	0.000323	0.216	-6.504	-2073.6	35.0	423	4.66	1
1-87227-3	26 Pin Connector	0.001	0.000323	0.216	-6.504	-2073.6	35.0	423	4.66	1

PiE	PiA	PiQ	PiR	PiS2	PiC
1	1.5	12	2	0.3	1

Pi P	Pi K
2.86	1.5
1.36	1.5
5.43	1.5
1.72	1.5
4.62	1.5
2.72	1.5

Circuit Board A: MIL-HDBK-217E Reliability Prediction

MISCELLANEOUS COMPONENTS, CONNECTORS, SOCKETS (Both Versions of CBA)

		Failure Rate	Lb	Pi E	Pi P
ES-7459-01-01-00	5 Socket Pins	0.001	0.00042	1	1.87
B14-AG11D	14 Pin Socket	0.001	0.00042	1	3.14
B14-AG11D	14 Pin Socket	0.001	0.00042	1	3.14
B14-AG11D	14 Pin Socket	0.001	0.00042	1	3.14
B14-AG11D	14 Pin Socket	0.001	0.00042	1	2.72
B14-AG11D	14 Pin Socket	0.001	0.00042	1	2.72
B14-AG11D	14 Pin Socket	0.001	0.00042	1	2.02
B14-AG11D	14 Pin Socket	0.001	0.00042	1	2.02
B16-AG11D	16 Pin Socket	0.001	0.00042	1	3.42
B16-AG11D	16 Pin Socket	0.001	0.00042	1	3.42
B20-AG11D	20 Pin Socket	0.002	0.00042	1	4.01
B20-AG11D	20 Pin Socket	0.002	0.00042	1	4.01
B20-AG11D	20 Pin Socket	0.002	0.00042	1	4.01
B20-AG11D	20 Pin Socket	0.002	0.00042	1	4.01
B20-AG11D	20 Pin Socket	0.002	0.00042	1	4.01
B20-AG11D	20 Pin Socket	0.002	0.00042	1	4.01
B20-AG11D	20 Pin Socket	0.002	0.00042	1	4.01
B24-AG11D	24 Pin Socket	0.002	0.00042	1	4.62
B24-AG11D	24 Pin Socket	0.002	0.00042	1	4.62
B24-AG11D	24 Pin Socket	0.002	0.00042	1	4.62
B24-AG11D	24 Pin Socket	0.002	0.00042	1	4.62
B28-AG11D	28 Pin Socket	0.002	0.00042	1	5.26
B28-AG11D	28 Pin Socket	0.002	0.00042	1	5.26
B28-AG11D	28 Pin Socket	0.002	0.00042	1	5.26
B40-AG11D	40 Pin Socket	0.003	0.00042	1	7.42
B40-AG11D	40 Pin Socket	0.003	0.00042	1	7.42

	Failure Rate	Lb	Pi Q	Pi E	N1	Pi C	Pi S	n2
Bare Printed Circuit Board	0.153	0.000041	2	1.00	1249	1.5	0	0

Circuit Board A: MIL-HDBK-217E Reliability Prediction

MISCELLANEOUS COMPONENTS, CONNECTORS, SOCKETS

Version 2 Only Components

		Failure Rate	Lb	A	X	Nt	T	To	P	Pi E
Amp 87578-7	20 Pin Connector	0.001	0.000323	0.216	-6.504	-2073.6	35.0	423	4.66	1

				Pi E	Pi P
814-AG11D	14 Pin Socket	0.001	0.00042	1	2.02
814-AG11D	14 Pin Socket	0.001	0.00042	1	2.02
820-AG11D	20 Pin Socket	0.002	0.00042	1	4.01
824-AG110	24 Pin Socket	0.002	0.00042	1	4.62
824-AG11D	24 Pin Socket	0.002	0.00042	1	4.62
828-AG11D	28 Pin Socket	0.002	0.00042	1	5.26
828-AG11D	28 Pin Socket	0.002	0.00042	1	5.26
828-AG11D	28 Pin Socket	0.002	0.00042	1	5.26
828-AG11D	28 Pin Socket	0.002	0.00042	1	5.26
840-AG11D	40 Pin Socket	0.003	0.00042	1	7.42

			Lb	Pi E	Pi Q
12 MHz	Crystal	0.048	0.023022	1	2.1

Miscellaneous Components Failure Rate 0.268 Version 1
0.318 Version 2

Remove from Version 2 Board

HM6264-LP15	RAM
840-AG11D	4 Sockets
828-AG11D	3 Sockets

Circuit Board A Predicted Failure Rate 17.169 Version 1
18.111 Version 2

Pi P	Pi K
2.86	1.5

CBA & CBB: A/D Convertor MIL-HDBK-217E Reliability Prediction

INTEGRATED CIRCUITS

Name	Function	Type	Failure Rate	# of Pins	Pi Q	C1	Pi T Pt	X	A	Tj	Tc
LF411	Op Amp	Bipolar	0.106	8	20	0.01	0.432	1.463	10429	38.000	35
OP27GP	Op Amp	Bipolar	0.121	8	20	0.01	0.507	1.624	10429	39.500	35
OP27GP	Op Amp	Bipolar	0.121	8	20	0.01	0.507	1.624	10429	39.500	35
LM301A	Op Amp	Bipolar	0.140	14	20	0.01	0.507	1.624	10429	39.500	35
LM319	Dual Comparator	Bipolar	0.261	14	20	0.01	1.109	2.406	10429	47.000	35
74LS04	Hex Invertor	LSTTL	0.088	14	20	0.01	0.247	0.904	6373	38.150	35
74LS08	Quad AND	LSTTL	0.091	14	20	0.01	0.262	0.964	6373	39.069	35
74LS51	Dual AND-OR	LSTTL	0.081	14	20	0.01	0.212	0.751	6373	35.840	35
74LS74	Dual D-Flip Flop	LSTTL	0.082	14	20	0.01	0.215	0.765	6373	36.050	35
74LS74	Dual D-Flip Flop	LSTTL	0.082	14	20	0.01	0.215	0.765	6373	36.050	35
74LS74	Dual D-Flip Flop	LSTTL	0.082	14	20	0.01	0.215	0.765	6373	36.050	35
74LS138	3 to 8 Decoder	LSTTL	0.138	16	20	0.01	0.459	1.524	6373	47.863	35
74LS151	Multiplexer	LSTTL	0.122	24	20	0.01	0.230	0.834	6373	37.100	35
74LS161	Counter	LSTTL	0.158	16	20	0.01	0.557	1.717	6373	51.012	35
74LS161	Counter	LSTTL	0.158	16	20	0.01	0.557	1.717	6373	51.012	35
74LS164	Shift Register	LSTTL	0.092	14	20	0.01	0.265	0.973	6373	39.200	35
74LS169	Counter	LSTTL	0.102	16	20	0.01	0.279	1.025	6373	40.000	35
74LS175	Quad D-Flip Flop	LSTTL	0.099	16	20	0.01	0.265	0.973	6373	39.200	35
74LS374	Octal Latch	LSTTL	0.117	20	20	0.01	0.279	1.027	6373	40.040	35
74LS590	Counter	LSTTL	0.124	16	20	0.01	0.386	1.352	6373	45.106	35
74LS697	Counter	LSTTL	0.137	20	20	0.01	0.381	1.337	6373	44.870	35
74LS697	Counter	LSTTL	0.137	20	20	0.01	0.381	1.337	6373	44.870	35
HI201	Quad Switch	CMOS	0.114	16	20	0.01	0.338	1.219	10429	35.750	35
HI201	Quad Switch	CMOS	0.114	16	20	0.01	0.338	1.219	10429	35.750	35
74HCT4040	Counter	CMOS	0.234	16	20	0.01	0.939	2.240	9270	48.125	35
ICM7209	Clock Generator	CMOS	0.092	8	20	0.01	0.363	1.290	9270	37.888	35

Failure Rate for ICs 3.192

thjc	P	Pi V	C2	Pi E	Pi L
50	0.060	1	0.0026	0.38	1
50	0.090	1	0.0026	0.38	1
50	0.090	1	0.0026	0.38	1
50	0.090	1	0.0051	0.38	1
50	0.24	1	0.0051	0.38	1
50	0.063	1	0.0051	0.38	1
50	0.081	1	0.0051	0.38	1
50	0.0168	1	0.0051	0.38	1
50	0.021	1	0.0051	0.38	1
50	0.021	1	0.0051	0.38	1
50	0.021	1	0.0051	0.38	1
50	0.257	1	0.0061	0.38	1
40	0.053	1	0.01	0.38	1
50	0.320	1	0.0061	0.38	1
50	0.320	1	0.0061	0.38	1
50	0.084	1	0.0051	0.38	1
50	0.100	1	0.0061	0.38	1
50	0.084	1	0.0061	0.38	1
40	0.126	1	0.006	0.38	1
50	0.202	1	0.0061	0.38	1
40	0.247	1	0.008	0.38	1
40	0.247	1	0.008	0.38	1
50	0.015	1	0.0061	0.38	1
50	0.015	1	0.0061	0.38	1
50	0.263	1	0.0061	0.38	1
50	0.058	1	0.0026	0.38	1

CBA & CBB: A/D Convertor MIL-HDBK-217E Reliability Prediction

RESISTORS & RESISTOR NETWORKS

Name	Function	Type	Failure Rate		Lambda b	Pi E	Pi R	Pi Q
10 Ohm	Resistor	Metal Film	0.023	2	0.0015	1	1	15
100 Ohm	Resistor	Metal Film	0.024	2	0.0016	1	1	15
100 Ohm	Resistor	Metal Film	0.024	2	0.0016	1	1	15
1 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
10 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
13 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
0 Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
0 Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
2 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
20 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
220 Ohm	Resistor	Metal Film	0.017	2	0.0011	1	1	15
270 Ohm	Resistor	Metal Film	0.015	2	0.001	1	1	15
27 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
3.3 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
3.6 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
390 Ohm	Resistor	Metal Film	0.013	2	0.00084	1	1	15
3.9 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
47 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
510 Ohm	Resistor	Metal Film	0.012	2	0.0008	1	1	15
5.1 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
56 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
6.8 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
6.8 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
680 K Ohm	Resistor	Metal Film	0.013	2	0.00076	1	1	15
5.1 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
100 Ohm	Resistor	Metal Film	0.023	2	0.0015	1	1	15
12.4 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
12.4 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
124 K Ohm	Resistor	Metal Film	0.013	2	0.00076	1	1	15
15 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
15 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
2.37 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
2.37 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
4.87 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
47.5 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
4.99 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
4.99 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
4.99 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
4.99 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
5.65 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
5.65 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15

CBA & CBB: A/D Convertor MIL-HDBK-217E Reliability Prediction

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RESISTORS & RESISTOR NETWORKS

Name	Function	Type	Failure Rate		Lambda b	Pi E	Pi R	Pi Q		
182 Ohm	Resistor	Metal Film	0.017	2	0.0011	1	1	15		
7.5 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15		
121 K Ohm	Resistor	Metal Film	0.013	2	0.00076	1	1.1	15		
1.5 k Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15		
499 Ohm	Resistor	Metal Film	0.012	2	0.0008	1	1	15		
499 Ohm	Resistor	Metal Film	0.012	2	0.0008	1	1	15		
						Pi Taps	Pi E	Pi R	Pi Q	Pi V
20 Ohm	Potentiometer	Metal Film		3		1	1	1	10	1.05
						Nr	Pi T	Pi E	Pi Q	
5.1 K Ohm	Resistor SIP	Metal Film	0.019	7	0.00066	6	1.56	1	3	
	Resistor SIP	Metal Film	0.019	7	0.00066	6	1.56	1	3	
	Failure Rate for Resistors		0.640							

CBA & CBU: A/D Convertor MIL-HDBK-217E Reliability Prediction

CAPACITORS

Name	Function	Type	Failure Rate	# of Pins	Lb	Pe E	Pi Q	Pi CV
0.01 uF	Capacitor	Ceramic	0.0084	2	0.00074	1	10	1.129233
0.01 uF	Capacitor	Ceramic	0.0084	2	0.00074	1	10	1.129233
0.01 uF	Capacitor	Ceramic	0.0084	2	0.00074	1	10	1.129233
0.01 uF	Capacitor	Ceramic	0.0084	2	0.00074	1	10	1.129233
0.01 uF	Capacitor	Ceramic	0.0084	2	0.00074	1	10	1.129233
0.01 uF	Capacitor	Ceramic	0.0084	2	0.00074	1	10	1.129233
0.01 uF	Capacitor	Ceramic	0.0084	2	0.00074	1	10	1.129233
0.01 uF	Capacitor	Ceramic	0.0084	2	0.00074	1	10	1.129233
0.01 uF	Capacitor	Ceramic	0.0084	2	0.00074	1	10	1.129233
0.01 uF	Capacitor	Ceramic	0.0084	2	0.00074	1	10	1.129233
0.01 uF	Capacitor	Ceramic	0.0084	2	0.00074	1	10	1.129233
0.01 uF	Capacitor	Ceramic	0.0084	2	0.00074	1	10	1.129233
18 pF	Capacitor	Ceramic	0.0079	2	0.0014	1	10	0.563460
18 pF	Capacitor	Ceramic	0.0079	2	0.0014	1	10	0.563460
18 pF	Capacitor	Ceramic	0.0079	2	0.0014	1	10	0.563460
100 pF	Capacitor	Ceramic	0.0050	2	0.00074	1	10	0.680430
100 pF	Capacitor	Ceramic	0.0050	2	0.00074	1	10	0.680430
220 pF	Capacitor	Ceramic	0.0055	2	0.00074	1	10	0.742079
220 pF	Capacitor	Ceramic	0.0055	2	0.00074	1	10	0.742079
220 pF	Capacitor	Ceramic	0.0055	2	0.00074	1	10	0.742079
470 pF	Capacitor	Ceramic	0.0060	2	0.00074	1	10	0.806704
680 pF	Capacitor	Ceramic	0.0118	2	0.0014	1	10	0.840155
680 pF	Capacitor	Ceramic	0.0118	2	0.0014	1	10	0.840155
0.1 uF	Capacitor	Ceramic	0.0108	2	0.00074	1	10	1.454734
0.1 uF	Capacitor	Ceramic	0.0108	2	0.00074	1	10	1.454734
0.1 uF	Capacitor	Ceramic	0.0108	2	0.00074	1	10	1.454734
0.1 uF	Capacitor	Ceramic	0.0108	2	0.00074	1	10	1.454734

Name	Function	Type	Failure Rate		Lambda b	Pi E	Pi SR	Pi Q	Pi CV
4.7 uF	Capacitor	Tantalum	0.008	2	0.0049	1	0.13	10	1.204
4.7 uF	Capacitor	Tantalum	0.008	2	0.0049	1	0.13	10	1.204
4.7 uF	Capacitor	Tantalum	0.008	2	0.0049	1	0.13	10	1.204
4.7 uF	Capacitor	Tantalum	0.008	2	0.0049	1	0.13	10	1.204
4.7 uF	Capacitor	Tantalum	0.008	2	0.0049	1	0.13	10	1.204
4.7 uF	Capacitor	Tantalum	0.008	2	0.0049	1	0.13	10	1.204
6.8 uF	Capacitor	Tantalum	0.008	2	0.0049	1	0.13	10	1.259
0.1 uF	Capacitor	Propylene	0.012	2	0.0012	1		10	0.970

Failure Rate for Capacitors 0.289

CBA & CBB: A/D Converter MIL-HDBK-217E Reliability Prediction

MISCELLANEOUS COMPONENTS, CONNECTORS, SOCKETS

Name	Function	Type	Failure Rate	# of Pins	Pi Q	C1	Pi T: Pt	X	A	Tj	Tc
S0211	Quad Switch	CMOS	0.311	16	20	0.01	0.513	1.635	10429	39.600	35
S0211	Quad Switch	CMOS	0.311	16	20	0.01	0.513	1.635	10429	39.600	35
IMF6485	Dual Amp	JFET	0.143	6	20	0.01	0.675	1.910	10429	42.200	35

Name	Function	Type	Failure Rate	# of Pins	Lb	A	Nt	Tm	P	DT	S
2N3906	PNP Transistor	Silicon	0.0272	3	0.001575	0.0648	-1324	448	14.2	150	0.3
2N3906	PNP Transistor	Silicon	0.0272	3	0.001575	0.0648	-1324	448	14.2	150	0.3
2N3904	NPN Transistor	Silicon	0.0213	3	0.001230	0.0189	-1052	448	10.5	150	0.4

Name	Function	Failure Rate	# of Pins	Lb	Pi E	Pi Q	Pi R	Pi A	Pi S2	Pi C
FOH300	Diode	0.002	2	0.00037	1	7.5	1	1.0	0.7	1
FOH300	Diode	0.002	2	0.00037	1	7.5	1	1.0	0.7	1
FOH300	Diode	0.002	2	0.00037	1	7.5	1	1.0	0.7	1
FOH300	Diode	0.002	2	0.00037	1	7.5	1	1.0	0.7	1
FOH300	Diode	0.002	2	0.00037	1	7.5	1	1.0	0.7	1
1N4148	Diode	0.002	2	0.00045	1	7.5	1	1.0	0.7	1
1N4148	Diode	0.002	2	0.00045	1	7.5	1	1.0	0.7	1
1N4148	Diode	0.004	2	0.00075	1	7.5	1	1.0	0.7	1
1N4148	Diode	0.004	2	0.00075	1	7.5	1	1.0	0.7	1
1N6263	Diode	0.003	2	0.00058	1	7.5	1	1.0	0.7	1
1N6263	Diode	0.003	2	0.00058	1	7.5	1	1.0	0.7	1
1N6263	Diode	0.003	2	0.00058	1	7.5	1	1.0	0.7	1
1N6263	Diode	0.003	2	0.00058	1	7.5	1	1.0	0.7	1
1N702A	Diode	0.002	2	0.00022	1	15	1	1.0	0.7	1
6.35V Ref	Diode	0.001	2	0.00017	1	7.5	1	1.0	0.7	1

Name	Function	Failure Rate	# of Pins	Lb	Pi E	Pi Q
2.4576 MHz	Crystal	0.034	2	0.015906	1	2.1

Name	Function	Failure Rate	# of Pins	Lb	A	X	Nt	T	To	P
1-86418-7	26 Pin Connector	0.002	26	0.000323	0.216	-6.504	-2073.6	35.0	423	4.66
1-86418-7	26 Pin Connector	0.001	26	0.000323	0.216	-6.504	-2073.6	35.0	423	4.66

Name	Failure Rate	Lb	Pi Q	Pi E	N1	Pi C	Pi S	n2
re Printed Circuit Board	0.074	0.000041	2	1.00	698	1.3	0	0

Miscellaneous Part Failure Rate	0.990
Total Assembly Failure Rate	5.111

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thjc	P	Pi V	C2	Pi E	Pi L
50	0.092	2.58	0.0061	0.38	1
50	0.092	2.58	0.0061	0.38	1
60	0.120	1.00	0.0011	0.38	1
PiE	PiA	PiQ	PiR	PiS2	PiC
1	1.5	12	2	0.48	1
1	1.5	12	2	0.48	1
1	1.5	12	2	0.48	1

Pi E	Pi P	Pi K
1	4.62	1.5
1	2.72	1.5

Circuit Board B: MIL-HDBK-217E Reliability Prediction

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INTEGRATED CIRCUITS

Name	Function	Type	Failure Rate	# of Pins	Pi Q	C1	Pi T Pt	X	H	T j	Tc
MC6802	Microprocessor	HMOS	1.193	40	20	0.03	1.747	2.861	8111	60.00 0	35
74LS32	Quad OR	LSTTL	0.085	14	20	0.01	0.230	0.834	6373	37.10 0	35
74LS244	Octal Buffer	LSTTL	0.127	20	20	0.01	0.331	1.197	6373	42.66 5	35
74LS244	Octal Buffer	LSTTL	0.127	20	20	0.01	0.331	1.197	6373	42.66 5	35
74LS244	Octal Buffer	LSTTL	0.127	20	20	0.01	0.331	1.197	6373	42.66 5	35
74LS240	Octal Invertor/Drvr	LSTTL	0.130	20	20	0.01	0.348	1.248	6373	43.47 0	35
74LS240	Octal Invertor/Drvr	LSTTL	0.130	20	20	0.01	0.348	1.248	6373	43.47 0	35
MC6821	PIA	NMOS	0.592	40	20	0.03	0.746	2.009	8111	48.75 0	35
74LS139	Decoder	LSTTL	0.087	16	20	0.01	0.204	0.714	6373	35.28 9	35
HM6264-LP15	8K x 8 RAM	CMOS	1.436	28	20	0.1	0.673	1.906	9270	44.45 0	35
LM339N	Quad Comparator	Bipolar	0.184	14	20	0.01	0.726	1.982	10429	42.89 5	35
74HCT374	Octal Latch	CMOS	0.544	20	20	0.01	2.418	3.186	9270	59.00 0	35
PMI OP-07EJ	Op Amp	Bipolar	0.091	8	20	0.01	0.378	1.331	7532	41.56 3	35
74LS138	Decoder	LSTTL	0.113	16	20	0.01	0.335	1.210	6373	42.87 5	35
AD940	DC/DC Convertor	Bipolar	0.431	5	20	0.01	2.099	3.044	10429	53.39 0	35
MP298	PGA		0.000	24							
MP8018A	A/D Convertor		5.111	52							

Integrated Circuits Failure Rate 10.509

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thjc	P	Pi V	C2	Pi E	Pi L
25	1.000	1	0.019	0.38	1
50	0.042	1	0.0051	0.38	1
40	0.192	1	0.008	0.38	1
40	0.192	1	0.008	0.38	1
40	0.192	1	0.008	0.38	1
40	0.212	1	0.0080	0.38	1
40	0.212	1	0.0080	0.38	1
25	0.550	1	0.019	0.38	1
5	0.058	1	0.0061	0.38	1
40	0.236	1	0.012	0.38	1
50	0.158	1	0.0051	0.38	1
40	0.600	1	0.008	0.38	1
50	0.131	1	0.002	0.38	1
50	0.158	1	0.0061	0.38	1
10	1.839	1	0.00145	0.38	1

Circuit Board 8: MIL-HDBK-217E Reliability Prediction

CAPACITORS

Name	Function	Type	Failure Rate	Lb	Pe E	Pi Q	Pi CV
10 uF, 100V	Capacitor	Electrolytic	0.0768	0.0155	1	10	0.4956
10 uF, 100V		Electrolytic	0.0768	0.0155	1	10	0.4956
10 uF, 100V		Electrolytic	0.0768	0.0155	1	10	0.4956
27 pF, 50 V	Capacitor	Ceramic	0.0046	0.00078	1	10	0.5891
27 pF, 50 V		Ceramic	0.0046	0.00078	1	10	0.5891
.01 uF, 50 V	Capacitor	Ceramic	0.0088	0.00078	1	10	1.1292
.01 uF, 50 V		Ceramic	0.0088	0.00078	1	10	1.1292
.01 uF, 50 V		Ceramic	0.0088	0.00078	1	10	1.1292
.01 uF, 50 V		Ceramic	0.0088	0.00078	1	10	1.1292
.01 uF, 50 V		Ceramic	0.0088	0.00078	1	10	1.1292
.01 uF, 50 V		Ceramic	0.0088	0.00078	1	10	1.1292
.01 uF, 50 V		Ceramic	0.0088	0.00078	1	10	1.1292
.01 uF, 50 V		Ceramic	0.0088	0.00078	1	10	1.1292
.01 uF, 50 V		Ceramic	0.0088	0.00078	1	10	1.1292
.01 uF, 50 V		Ceramic	0.0088	0.00078	1	10	1.1292
.01 uF, 50 V		Ceramic	0.0088	0.00078	1	10	1.1292
.01 uF, 50 V		Ceramic	0.0088	0.00078	1	10	1.1292
.01 uF, 50 V		Ceramic	0.0088	0.00078	1	10	1.1292
.01 uF, 50 V		Ceramic	0.0088	0.00078	1	10	1.1292
.01 uF, 50 V		Ceramic	0.0088	0.00078	1	10	1.1292
.01 uF, 50 V		Ceramic	0.0088	0.00078	1	10	1.1292
.01 uF, 50 V		Ceramic	0.0088	0.00078	1	10	1.1292
.01 uF, 50 V		Ceramic	0.0088	0.00078	1	10	1.1292
.01 uF, 50 V		Ceramic	0.0088	0.00078	1	10	1.1292
.01 uF, 50 V		Ceramic	0.0068	0.00078	1	10	1.1292
.01 uF, 50 V		Ceramic	0.0088	0.00078	1	10	1.1292
.01 uF, 50 V		Ceramic	0.0088	0.00078	1	10	1.1292
.01 uF, 50 V		Ceramic	0.0088	0.00078	1	10	1.1292
47 uF, 50 V	Capacitor	Ceramic	0.0223	0.00078	1	10	2.8622
0.1 uF, 50 V	Capacitor	Ceramic	0.0099	0.00068	1	10	1.4547
0.1 uF, 50 V		Ceramic	0.0099	0.00068	1	10	1.4547

Capacitors Failure Rate 0.484

Circuit Board B: MIL-HDBK-217E Reliability Prediction

RESISTORS

Name	Function	Type	Failure Rate	Lb	A	B	T	Nt	G	S
20K, 0.1 W	Resistor	Metal Film	0.011	0.00075	0.000325	1	35	343	3	0.045
20K, 0.1 W		Metal Film	0.011	0.00075	0.000325	1	35	343	3	0.0001
10K, 0.1 W	Resistor	Metal Film	0.011	0.00075	0.000325	1	35	343	3	0.0025
10K, 0.1 W		Metal Film	0.011	0.00075	0.000325	1	35	343	3	0.0025
10K, 0.1 W		Metal Film	0.011	0.00075	0.000325	1	35	343	3	0.0025
3.3K, 0.25 W	Resistor	Carbon Film	0.011	0.00075	0.000325	1	35	343	3	0.0303
3.3K, 0.25 W		Carbon Film	0.011	0.00075	0.000325	1	35	343	3	0.0303
3.3K, 0.25 W		Carbon Film	0.011	0.00075	0.000325	1	35	343	3	0.0075
3.3K, 0.25 W		Carbon Film	0.011	0.00075	0.000325	1	35	343	3	0.0075
3.3K, 0.25 W		Carbon Film	0.013	0.00084	0.000325	1	35	343	3	0.1212
3.3K, 0.25 W		Carbon Film	0.013	0.00084	0.000325	1	35	343	3	0.1212
100, 0.25W	Resistor	Carbon Film	0.032	0.0021	0.000325	1	35	343	3	1.00
100, 0.25W		Carbon Film	0.032	0.0021	0.000325	1	35	343	3	1.00
100, 0.25W		Carbon Film	0.032	0.0021	0.000325	1	35	343	3	1.00
100, 0.25W		Carbon Film	0.032	0.0021	0.000325	1	35	343	3	1.00
100, 0.25W		Carbon Film	0.032	0.0021	0.000325	1	35	343	3	1.00
100, 0.25W		Carbon Film	0.032	0.0021	0.000325	1	35	343	3	1.00
100, 0.25W		Carbon Film	0.032	0.0021	0.000325	1	35	343	3	1.00
100, 0.25W		Carbon Film	0.032	0.0021	0.000325	1	35	343	3	1.00
82, 0.25 W	Resistor	Carbon Film	0.023	0.0015	0.000325	1	35	343	3	0.7043
82, 0.25 W		Carbon Film	0.023	0.0015	0.000325	1	35	343	3	0.7043
82, 0.25 W		Carbon Film	0.023	0.0015	0.000325	1	35	343	3	0.7043
82, 0.25 W		Carbon Film	0.023	0.0015	0.000325	1	35	343	3	0.7043
10K, 0.25 W	Resistor	Carbon Film	0.011	0.00075	0.000325	1	35	343	3	0.0025
10K, 0.25 W		Carbon Film	0.011	0.00075	0.000325	1	35	343	3	0.0025
10K, 0.25 W		Carbon Film	0.011	0.00075	0.000325	1	35	343	3	0.0025
10K, 0.25 W		Carbon Film	0.011	0.00075	0.000325	1	35	343	3	0.0025
10K, 0.25 W		Carbon Film	0.011	0.00075	0.000325	1	35	343	3	0.0025
10K, 0.25 W		Carbon Film	0.011	0.00075	0.000325	1	35	343	3	0.0025
10K, 0.25 W		Carbon Film	0.011	0.00075	0.000325	1	35	343	3	0.0025
10K, 0.25 W		Carbon Film	0.011	0.00075	0.000325	1	35	343	3	0.0025
[illegible]0K, 0.25 W		Carbon Film	0.011	0.00075	0.000325	1	35	343	3	0.0025
[illegible]0K, 0.25 W		Carbon Film	0.011	0.00075	0.000325	1	35	343	3	0.0025
[illegible]0K, 0.25 W	Resistor	Carbon Film	0.011	0.00075	0.000325	1	35	343	3	0.0012
[illegible]0K, 0.25 W		Carbon Film	0.011	0.00075	0.000325	1	35	343	3	0.0012
[illegible]0K, 0.25 W		Carbon Film	0.011	0.00075	0.000325	1	35	343	3	0.0012
[illegible]0K, 0.25 W		Carbon Film	0.011	0.00075	0.000325	1	35	343	3	0.0012

Ns	J	H	Pi E	Pi R	Pi Q
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15
1	1	1	1	1	15

Circuit Board B: MIL-HDBK-217E Reliability Prediction

RESISTORS & RESISTOR NETWORKS

Name	Function	Type	Failure Rate	Lb	A	B	T	Nt	G	S
1M, 0.25 W	Resistor	Carbon Film	0.012	0.00075	0.000325	1	35	343	3	0.0001
1M, 0.25 W		Carbon Film	0.012	0.00075	0.000325	1	35	343	3	0.0001
1M, 0.25 W		Carbon Film	0.012	0.00075	0.000325	1	35	343	3	0.0001
1M, 0.25 W		Carbon Film	0.012	0.00075	0.000325	1	35	343	3	0.0001
1M, 0.25 W		Carbon Film	0.012	0.00075	0.000325	1	35	343	3	0.0001
1M, 0.25 W		Carbon Film	0.012	0.00075	0.000325	1	35	343	3	0.0001
1M, 0.25 W		Carbon Film	0.012	0.00075	0.000325	1	35	343	3	0.0001
1M, 0.25 W		Carbon Film	0.012	0.00075	0.000325	1	35	343	3	0.0001
1M, 0.25 W		Carbon Film	0.012	0.00075	0.000325	1	35	343	3	0.0001
1M, 0.25 W		Carbon Film	0.012	0.00075	0.000325	1	35	343	3	0.0001
1M, 0.25 W		Carbon Film	0.012	0.00075	0.000325	1	35	343	3	0.0001
1M, 0.25 W		Carbon Film	0.012	0.00075	0.000325	1	35	343	3	0.0001
	Resistors Failure Rate		0.774							

Ns	J	H	Pi E	Pi R	Pi Q
1	1	1	1	1.1	15
1	1	1	1	1.1	15
1	1	1	1	1.1	15
1	1	1	1	1.1	15
1	1	1	1	1.1	15
1	1	1	1	1.1	15
1	1	1	1	1.1	15
1	1	1	1	1.1	15
1	1	1	1	1.1	15
1	1	1	1	1.1	15
1	1	1	1	1.1	15
1	1	1	1	1.1	15

Circuit Board 8: MIL-HDBK-217E Reliability Prediction
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MISCELLANEOUS COMPONENTS, CONNECTORS, SOCKETS

Name	Function	Type	Failure Rate	Lb	Pi E	Pi Q
4 MHz	Crystal		0.038	0.017882	1	2.1

Name	Function	Type	Failure Rate	Lb	Pi E	Pi P
3 87516-5	6 Pin Connector		0.001	0.00042	1	2.02
3 87516-5	6 Pin Connector		0.001	0.00042	1	2.02
3 87516-5	6 Pin Connector		0.001	0.00042	1	2.02
3 87516-5	6 Pin Connector		0.001	0.00042	1	2.02
3 87516-5	6 Pin Connector		0.001	0.00042	1	2.02
3M 3432-1302	40 Pin Connector		0.003	0.00042	1	7.42
AMP 1-86418-7	26 Pin Connector		0.002	0.00042	1	4.94
AMP 1-86418-	26 Pin Connector		0.002	0.00042	1	4.94
AMP 1-87215-1	4 Pin Connector		0.001	0.00042	1	1.87
AMP 87215-5	16 Pin Connector		0.001	0.00042	1	3.42

Name	Function	Type	Failure Rate	Lb	Pi E	Pi P
814-AG110	14 Pin Socket		0.001	0.00042	1	3.14
820-AG110	20 Pin Socket		0.002	0.00042	1	4.01
820-AG110	20 Pin Socket		0.002	0.00042	1	4.01
820-AG110	20 Pin Socket		0.002	0.00042	1	4.01
820-AG110	20 Pin Socket		0.002	0.00042	1	4.01
820-AG110	20 Pin Socket		0.002	0.00042	1	4.01
820-AG110	20 Pin Socket		0.002	0.00042	1	4.01
828-AG110	28 Pin Socket		0.002	0.00042	1	5.26
828-AG110	28 Pin Socket		0.002	0.00042	1	5.26
840-AG110	40 Pin Socket		0.003	0.00042	1	7.42
840-AG110	40 Pin Socket		0.003	0.00042	1	7.42
TO-3	2 Pin Socket		0.001	0.00042	1	1.87

	Failure Rate	Lb	Pi Q	Pi C	n1	Pi U	Pi S	n2
Bare Printed Circuit Board	0.140	0.000041	2	1.00	852	2.0	0	0

Miscellaneous Components Failure Rate 0.214

Circuit Board 8 Predicted Failure Rate 11.982

Circuit Board B: Programmable Gain Amplifier MIL-HDBK-217E Reliability Prediction

INTEGRATED CIRCUITS

Name	Function	Type	Failure Rate	# of Pins	Pi Q	Cl	Pi T Pt	X	A	Tj	Tc
4052B	Multiplexer	CMOS	0.102	16	20	0.01	0.277	1.017	9270	35.075	35
LF 412 CN	Op Amp	Bipolar	0.049	8	10	0.01	0.418	1.431	10429	37.700	35
DAC-08E	D/A Convertor	Bipolar	0.121	16	20	0.01	0.373	1.317	10429	36.650	35
AM25L03PC	Suc. App. Reg.	TTL	0.094	16	20	0.01	0.238	0.865	5214	40.500	35
74HCT273	Oct D Flip-Flop	CMOS	0.117	20	20	0.01	0.279	1.026	9270	35.160	35
4053B	Triple 2 Ch Mux	CMOS	0.102	16	20	0.01	0.277	1.017	9270	35.075	35
4093B	Schmitt Trigger	CMOS	0.099	14	20	0.01	0.300	1.098	9270	35.900	35
LM308A	Op Amp	Bipolar	0.084	8	20	0.01	0.319	1.161	10429	35.225	35
4051B	8 Ch Analog Mux	CMOS	0.102	16	20	0.01	0.277	1.017	9270	35.075	35

Integrated Circuit Failure Rate 0.868

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thjc	P	Pi V	C2	Pi E	Pi L
50	0.001	1	0.0061	0.38	1
50	0.054	1	0.002	0.38	1
50	0.033	1	0.0061	0.38	1
50	0.11	1	0.0061	0.38	1
40	0.004	1	0.008	0.38	1
50	0.0015	1	0.0061	0.38	1
50	0.018	1	0.0051	0.38	1
50	0.0045	1	0.0026	0.38	1
50	0.001	1	0.0061	0.38	1

Circuit Board B: Programmable Gain Amplifier MIL-HDBK-217E Reliability Prediction

RESISTORS & RESISTOR NETWORKS

Name	Function	Type	Failure Rate	#of Pins	Lambda b	Pi E	Pi R	Pi Q
1 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
1 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
1 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
1 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
100 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
100 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
100 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
100 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
100 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
100 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
100 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
100 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
100 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
10 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
10 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
10 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
10 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
10 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
10 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
10 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
10 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
240 K Ohm	Resistor	Metal Film	0.013	2	0.00076	1	1.1	15
5.1 K Ohm	Resistor	Metal Film	0.013	2	0.00076	1	1.1	15
5.1 K Ohm	Resistor	Metal Film	0.013	2	0.00076	1	1.1	15
5.1 K Ohm	Resistor	Metal Film	0.013	2	0.00076	1	1.1	15
330 K Ohm	Resistor	Metal Film	0.013	2	0.00076	1	1.1	15
330 K Ohm	Resistor	Metal Film	0.013	2	0.00076	1	1.1	15
2.7 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
2.7 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15

Circuit Board B: Programmable Gain Amplifier MIL-HDBK-217E Reliability Prediction

RESISTORS & RESISTOR NETWORKS

Name	Function	Type	Failure Rate	#of Pins	Lambda b	Pi E	Pi R	Pi Q
680 Ohm	Resistor	Metal Film	0.012	2	0.00083	1	1	15
680 Ohm	Resistor	Metal Film	0.012	2	0.00083	1	1	15
750 Ohm	Resistor	Metal Film	0.012	2	0.00083	1	1	15
2.4 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
3.0 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
1 M Ohm	Resistor	Metal Film	0.013	2	0.00076	1	1.1	15
33 Ohm	Resistor	Metal Film	0.026	2	0.0017	1	1	15
62 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
62 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
3.92 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
42.2 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
499 Ohm	Resistor	Metal Film	0.013	2	0.00086	1	1	15
4.87 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
4.99 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
1 M Ohm	Resistor	Metal Film	0.013	2	0.00076	1	1.1	15
1 M Ohm	Resistor	Metal Film	0.013	2	0.00076	1	1.1	15
1 M Ohm	Resistor	Metal Film	0.013	2	0.00076	1	1.1	15
2 K Ohm	Resistor	Metal Film	0.011	2	0.00076	1	1	15
					Lb	Nr	Pi f	Pi E
10 Pin	Resistor SIP	" "	0.028	7	0.00066	9	1.56	1
8 Pin	Resistor SIP	" "	0.022	7	0.00066	7	1.56	1

Resistors Failure Rate 0.615

Circuit Board 8: Programmable Gain Amplifier MIL-HDBK-217E Reliability Prediction

CAPACITORS

Name	Function	Type	Failure Rate	# of Pins	Lb	Pe E	Pi Q	Pi CV
.01 uF, 50	Capacitor	Ceramic	0.0076	2	0.00067	1	10	1.129233
0.022 uF	Capacitor	Ceramic	0.0084	2	0.00068	1	10	1.231545
15 pF, 50V	Capacitor	Ceramic	0.0037	2	0.00067	1	10	0.552273
0.1 uF	Capacitor	Ceramic	0.0099	2	0.00068	1	10	1.454734
1000 pF	Capacitor	Ceramic	0.0059	2	0.00067	1	10	0.876564
1000 pF	Capacitor	Ceramic	0.0059	2	0.00067	1	10	0.876564
1000 pF	Capacitor	Ceramic	0.0059	2	0.00067	1	10	0.876564
0.1 Uf	Capicator	Poly-Carbonate	0.0186	2	0.00057	1	30	1.088788

Name	Function	Type	Failure Rate	# of Pins	Lb	Pi E	Pi SR	Pi Q	Pi CV
6.8 uF	Capacitor	Tantalum	0.0082	2	0.0063	1	0.13	10	1.259
6.8 uF	Capacitor	Tantalum	0.0082	2	0.0063	1	0.13	10	1.259
6.8 uF	Capacitor	Tantalum	0.0082	2	0.0063	1	0.13	10	1.259

Capacitors Failure Rate 0.090

Circuit Board 8: Programmable Gain Amplifier MIL-HDBK-217E Reliability Prediction

MISCELLANEOUS COMPONENTS, CONNECTORS, SOCKETS

Name	Function	Type	Failure Rate	# of Pins	Lb	A	Nt	Tm	P	DT	S
2N3906	PNP Transistor	Silicon	0.0272	3	0.001575	0.0648	-1324	448	14.2	150	0.3
2N3906	PNP Transistor	Silicon	0.0272	3	0.001575	0.0648	-1324	448	14.2	150	0.3
2N3906	PNP Transistor	Silicon	0.0272	3	0.001575	0.0648	-1324	448	14.2	150	0.3
2N3906	PNP Transistor	Silicon	0.0272	3	0.001575	0.0648	-1324	448	14.2	150	0.3
2N3906	PNP Transistor	Silicon	0.0272	3	0.001575	0.0648	-1324	448	14.2	150	0.3
2N3906	PNP Transistor	Silicon	0.0272	3	0.001575	0.0648	-1324	448	14.2	150	0.3
2N3906	PNP Transistor	Silicon	0.0272	3	0.001575	0.0648	-1324	448	14.2	150	0.3
2N3906	PNP Transistor	Silicon	0.0272	3	0.001575	0.0648	-1324	448	14.2	150	0.3
2N3904	NPN Transistor	Silicon	0.0213	3	0.001230	0.0189	-1052	448	10.5	150	0.4
2N3904	NPN Transistor	Silicon	0.0213	3	0.001230	0.0189	-1052	448	10.5	150	0.4
2N3904	NPN Transistor	Silicon	0.0213	3	0.001230	0.0189	-1052	448	10.5	150	0.4

			Failure Rate		Lb	Pi E	Pi A	Pi Q	Pi C
J177	P Channel JFET	Silicon	0.396	3	0.022	1	1.5	12	1

		Failure Rate		Lb	Pi E	Pi Q	Pi R	Pi A	Pi S2	Pi C
FDH300	Diode	0.002	2	0.00037	1	7.5	1	1.0	0.2	1
"	Diode	0.002	2	0.00037	1	7.5	1	1.0	0.7	1
1N4148	Diode	0.002	2	0.00045	1	7.5	1	1.0	0.7	1
1N6263	Diode	0.003	2	0.00058	1	7.5	1	1.0	0.7	1
"	Diode	0.003	2	0.00058	1	7.5	1	1.0	0.7	1

		Failure Rate		Lb	Pi E	Pi A	Pi Q
1N753A	Zener Diode	0.009	2	0.00057	1	1	15
1N758A	Zener Diode	0.009	2	0.00057	1	1	15
1N746A	Zener Diode	0.009	2	0.00057	1	1	15
1N961B	Zener Diode	0.009	2	0.00057	1	1	15
1N961B	Zener Diode	0.009	2	0.00057	1	1	15
1N961B	Zener Diode	0.009	2	0.00057	1	1	15
1N961B	Zener Diode	0.009	2	0.00057	1	1	15

	Failure Rate		Lb	A	X	Nt	T	To	P
24 Socket Pins	0.002	24	0.000323	0.216	-6.504	-3073.6	35.0	423	4.66

	Failure Rate	Lb	Pi Q	Pi E	N1	Pi C	Pi S	n2
are Printed Circuit Board	0.028	0.000041	2	1.00	344	1.0	0	0

Miscellaneous Parts Failure Rate 0.780

Total Device Failure Rate 2.354

PiE	PiA	PiQ	PiR	PiS2	PiC
1	1.5	12	2	0.48	1
1	1.5	12	2	0.48	1
1	1.5	12	2	0.48	1
1	1.5	12	2	0.48	1
1	1.5	12	2	0.48	1
1	1.5	12	2	0.48	1
1	1.5	12	2	0.48	1
1	1.5	12	2	0.48	1
1	1.5	12	2	0.48	1
1	1.5	12	2	0.48	1
1	1.5	12	2	0.48	1

Pi E	Pi P	Pi K
1	4.62	1.5

Appendix C. Mil-Hdbk-217E Failure Rate Predictions of CBA & CBB With Adjusted π Factors

APPENDIX C
Circuit Board A: MIL-HDBK-217E Reliability Prediction
============================== With Adjusted Pi Factors
INTEGRATED CIRCUITS

Name	Function	Type	Usage	Failure Rate	# of Pins	Pi Q	C1	Pi T Pt	X	A	Tj	Tc
LM339N	Quad Comparator	Bipolar	0.75	0.062	14	6.54	0.01	0.698	1.943	10429	42.519	35
74LS154	Decoder	LSTTL	1.00	0.048	24	6.54	0.01	0.241	0.881	6373	37.800	35
74LS32	Quad OR	LSTTL	1.00	0.032	14	6.54	0.01	0.229	0.828	6373	37.000	35
74LS02	Quad NOR	LSTTL	1.00	0.031	14	6.54	0.01	0.215	0.766	6373	36.075	35
74LS08	Quad AND	LSTTL	0.75	0.031	14	6.54	0.01	0.224	0.808	6373	36.700	35
74LS139	Decoder	LSTTL	1.00	0.036	16	6.54	0.01	0.240	0.877	6373	37.750	35
AD940	DC/DC Convertor	Bipolar	1.00	1.440	5	6.54	0.01	2.099	3.044	10429	53.390	35
74LS175	Quad D-FF Latch	LSTTL	1.00	0.038	16	6.54	0.01	0.270	0.992	6373	39.500	35
74LS244	Octal Buffer	LSTTL	1.00	0.047	20	6.54	0.01	0.323	1.173	6373	42.300	35
74LS244	Octal Buffer	LSTTL	1.00	0.047	20	6.54	0.01	0.323	1.173	6373	42.300	35
74LS244	Octal Buffer	LSTTL	1.00	0.047	20	6.54	0.01	0.323	1.173	6373	42.300	35
74LS244	Octal Buffer	LSTTL	1.00	0.047	20	6.54	0.01	0.323	1.173	6373	42.300	35
74LS14	Hex Invertor (ST)	LSTTL	1.00	0.034	14	6.54	0.01	0.272	1.000	6373	39.625	35
74LS245	Octal Bus Tranceiver	LSTTL	1.00	0.065	20	6.54	0.01	0.591	1.777	6373	52.000	35
74LS373	Octal Latch	LSTTL	1.00	0.048	20	6.54	0.01	0.338	1.218	6373	43.000	35
MP8018A	A/D Convertor	Hybrid	1.00	1.418	26							
8255A-5	Intel PPI	NMOS	1.00	0.197	40	6.54	0.03	0.822	2.107	8111	50.000	35
8259A	Intel PIC	NMOS	0.50	0.214	28	6.54	0.03	0.888	2.184	8111	51.000	35
8253	Prog Intrv Tmr	HMOS	1.00	0.459	24	6.54	0.03	2.172	3.078	8111	63.000	35
8085	CPU	HMOS	1.00	0.249	40	6.54	0.03	0.950	2.252	8111	51.875	35
HM6116P-4	2K x 8 RAM	CMOS	1.00	0.199	24	6.54	[illegible]	1.016	2.319	9270	49.000	35
HM6116P-4	2K x 8 RAM	CMOS	1.00	0.199	24	6.54	[illegible]	1.016	2.319	9270	49.000	35
HM6264-LP15	8K x 8 RAM	CMOS	1.00	0.250	28	6.54	0.05	0.645	1.864	9270	44.000	35
27C64-3	8K x 8 EPROM	CMOS	1.00	0.171	28	6.54	0.05	0.404	1.396	9270	39.000	35
74LS04	Hex Invertor	TTL	0.33	0.034	14	6.54	0.01	0.272	1.000	6373	39.625	35
UA78H05ASC	Voltage Regulator	Bipolar	1.00	0.598	2	6.54	0.01	9.125	4.514	10429	69.125	35

Version 2 Only Components
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Name	Function	Type	Usage	Failure Rate	# of Pins	Pi Q	C1	Pi T Pt	X	A	Tj	Tc
74LS373	Octal Latch	TTL	1.00	0.042	20	6.54	0.01	0.338	1.218	6373	43.000	35
74LS244	Octal Buffer	TTL	1.00	0.041	20	6.54	0.01	0.323	1.173	6373	42.300	35
7406	Hex Invertor	TTL	0.33	0.028	14	6.54	0.01	0.239	0.872	5214	40.625	35
80C31	8 Bit uController	CMOS	0.30	0.185	40	6.54	[illegible]	0.350	1.252	9270	37.500	35
74HC14	Hex Invertor	CMOS	0.33	0.049	14	6.54	0.01	0.562	1.725	9270	42.500	35
MC3479P	Stepper Driver	Bipolar	1.00	0.113	16	6.54	0.01	1.5	2.709	10429	50.000	35

Version 1 Failure Rate	6.043
Version 2 Failure Rate	6.502

Circuit Board A: MIL-HDBK-217E Reliability Prediction
With Adjusted Pi Factors

INTEGRATED CIRCUITS

thjc	P	Pi V	C2	Pi E	Pi L
50	0.150	1	0.0051	0.5	1
40	0.070	1	0.01	0.5	1
50	0.040	1	0.0051	0.5	1
50	0.022	1	0.0051	0.5	1
50	0.034	1	0.0051	0.5	1
50	0.055	1	0.0061	0.5	1
10	1.839	1	0.00145	0.5	
50	0.090	1	0.0061	0.5	1
40	0.183	1	0.008	0.5	1
40	0.183	1	0.008	0.5	1
40	0.183	1	0.008	0.5	1
40	0.183	1	0.008	0.5	1
50	0.093	1	0.0051	0.5	1
40	0.425	1	0.008	0.5	1
40	0.200	1	0.008	0.5	1
25	0.600	1	0.011	0.5	1
40	0.400	1	0.012	0.5	1
40	0.700	1	0.01	0.5	1
25	0.675	1	0.019	0.5	1
40	0.350	1	0.01	0.5	1
40	0.350	1	0.01	0.5	1
40	0.225	1	0.012	0.5	1
40	0.100	1	0.012	0.5	1
50	0.093	1	0.0051	0.5	1
5	6.825	1	0.0003	0.5	1

thjc	P	Pi V	C2	Pi E	Pi L
40	0.200	1	0.008	0.38	1
40	0.183	1	0.008	0.38	1
50	0.113	1	0.0051	0.38	1
25	0.100	1	0.019	0.38	1
50	0.150	1	0.0051	0.38	1
50	0.300	1	0.0061	0.38	1

APPENDIX C

CBA & CBB: A/D Convertor MIL-HDBK-217E Reliability Prediction
========================== With Adjusted Pi Factors

INTEGRATED CIRCUITS

Name	Function	Type	Usage	Failure Rate	# of Pins	Pi Q	C1	Pi T Pt	X	A	Tj
LF411	Op Amp	Bipolar	1.00	0.037	8	6.54	0.01	0.432	1.463	10429	38.000
OP27GP	Op Amp	Bipolar	1.00	0.042	8	6.54	0.01	0.507	1.624	10429	39.500
OP27GP	Op Amp	Bipolar	1.00	0.042	8	6.54	0.01	0.507	1.624	10429	39.500
LM301A	Op Amp	Bipolar	1.00	0.050	14	6.54	0.01	0.507	1.624	10429	39.500
LM319	Dual Comparator	Bipolar	1.00	0.089	14	6.54	0.01	1.109	2.406	10429	47.000
74LS04	Hex Invertor	LSTTL	1.00	0.033	14	6.54	0.01	0.247	0.904	6373	38.150
74LS08	Quad AND	LSTTL	1.00	0.034	14	6.54	0.01	0.262	0.964	6373	39.069
74LS51	Dual AND-OR	LSTTL	1.00	0.031	14	6.54	0.01	0.212	0.751	6373	35.840
74LS74	Dual D-Flip Flop	LSTTL	1.00	0.031	14	6.54	0.01	0.215	0.765	6373	36.050
74LS74	Dual D-Flip Flop	LSTTL	1.00	0.031	14	6.54	0.01	0.215	0.765	6373	36.050
74LS74	Dual D-Flip Flop	LSTTL	1.00	0.031	14	6.54	0.01	0.215	0.765	6373	36.050
74LS138	3 to 8 Decoder	LSTTL	1.00	0.050	16	6.54	0.01	0.459	1.524	6373	47.863
74LS151	Multiplexer	LSTTL	1.00	0.048	24	6.54	0.01	0.230	0.834	6373	37.100
74LS161	Counter	LSTTL	1.00	0.056	16	6.54	0.01	0.557	1.717	6373	51.012
74LS161	Counter	LSTTL	1.00	0.056	16	6.54	0.01	0.557	1.717	6373	51.012
74LS164	Shift Register	LSTTL	1.00	0.034	14	6.54	0.01	0.265	0.973	6373	39.200
74LS169	Counter	LSTTL	1.00	0.038	16	6.54	0.01	0.279	1.025	6373	40.000
74LS175	Quad D-Flip Flop	LSTTL	1.00	0.037	16	6.54	0.01	0.265	0.973	6373	39.200
74LS374	Octal Latch	LSTTL	1.00	0.044	20	6.54	0.01	0.279	1.027	6373	40.040
74LS590	Counter	LSTTL	1.00	0.045	16	6.54	0.01	0.386	1.352	6373	45.106
74LS697	Counter	LSTTL	1.00	0.051	20	6.54	0.01	0.381	1.337	6373	44.870
74LS697	Counter	LSTTL	1.00	0.051	20	6.54	0.01	0.381	1.337	6373	44.870
HI201	Quad Switch	CMOS	1.00	0.042	16	6.54	0.01	0.338	1.219	10429	35.750
HI201	Quad Switch	CMOS	1.00	0.042	16	6.54	0.01	0.338	1.219	10429	35.750
74HCT4040	Counter	CMOS	1.00	0.081	16	6.54	0.01	0.939	2.240	9270	48.125
ICM7209	Clock Generator	CMOS	1.00	0.032	8	6.54	0.01	0.363	1.290	9270	37.888
SD211	Quad Switch	CMOS	1.00	0.106	16	6.54	0.01	0.513	1.635	10429	39.600
"	Quad Switch	CMOS	1.00	0.106	16	6.54	0.01	0.513	1.635	10429	39.600
IMF6485	Dual Amp	JFET	1.00	0.048	6	6.54	0.01	0.675	1.910	10429	42.200

Adjusted Failure Rate 1.418

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Tc	thjc	P	Pi V	C2	Pi E	Pi L
35	50	0.060	1	0.0026	0.5	1
35	50	0.090	1	0.0026	0.5	1
35	50	0.090	1	0.0026	0.5	1
35	50	0.090	1	0.0051	0.5	1
35	50	0.24	1	0.0051	0.5	1
35	50	0.063	1	0.0051	0.5	1
35	50	0.081	1	0.0051	0.5	1
35	50	0.0168	1	0.0051	0.5	1
35	50	0.021	1	0.0051	0.5	1
35	50	0.021	1	0.0051	0.5	1
35	50	0.021	1	0.0051	0.5	1
35	50	0.257	1	0.0061	0.5	1
35	40	0.053	1	0.01	0.5	1
35	50	0.320	1	0.0061	0.5	1
35	50	0.320	1	0.0061	0.5	1
35	50	0.084	1	0.0051	0.5	1
35	50	0.100	1	0.0061	0.5	1
35	50	0.084	1	0.0061	0.5	1
35	40	0.126	1	0.008	0.5	1
35	50	0.202	1	0.0061	0.5	1
35	40	0.247	1	0.008	0.5	1
35	40	0.247	1	0.008	0.5	1
35	50	0.015	1	0.0061	0.5	1
35	50	0.015	1	0.0061	0.5	1
35	50	0.263	1	0.0061	0.5	1
35	50	0.058	1	0.0026	0.5	1
35	50	0.092	2.58	0.0061	0.5	1
35	50	0.092	2.58	0.0061	0.5	1
35	60	0.120	1.00	0.0011	0.5	1

APPENDIX C
Circuit Board 8: MIL-HDBK-217E Reliability Prediction
================================ With Adjusted Pi Factors
INTEGRATED CIRCUITS

Name	Function	Type	Usage	Failure Rate	# of Pins	Pi Q	C1	Pi T Pt	X	A	Tj	Tc
MC6802	Microprocessor	HMOS	1.00	0.390	40	6.54	0.03	1.747	2.861	8111	60.C 100	35
74LS32	Quad OR	LSTTL	1.00	0.028	14	6.54	0.01	0.230	0.834	6373	37.1 00	35
74LS244	Octal Buffer	LSTTL	1.00	0.042	20	6.54	0.01	0.331	1.197	6373	42.E 65	35
74LS244	Octal Buffer	LSTTL	1.00	0.042	20	6.54	0.01	0.331	1.197	6373	42.E 65	35
74LS244	Octal Buffer	LSTTL	1.00	0.042	20	6.54	0.01	0.331	1.197	6373	42.E 65	35
74LS240	Octal Invertor/Drvr	LSTTL		0.043	20	6.54	0.01	0.348	1.248	6373	43.4 70	35
74LS240	Octal Invertor/Drvr	LSTTL		0.043	20	6.54	0.01	0.348	1.248	6373	43.4 70	35
MC6821	PIA	NMOS	1.00	0.194	40	6.54	0.03	0.746	2.009	8111	48.7 '50	35
74LS139	Decoder	LSTTL	1.00	0.029	16	6.54	0.01	0.204	0.714	6373	35.2 '89	35
HM6264-LP15	8K x 8 RAM	CMOS	1.00	0.470	28	6.54	0.1	0.673	1.906	9270	44.4 50	35
LM339N	Quad Comparator	Bipolar	0.75	0.060	14	6.54	0.01	0.726	1.982	10429	42.E 195	35
74HCT374	Octal Latch	CMOS		0.178	20	6.54	0.01	2.418	3.186	9270	59.C 100	35
PMI OP-07EJ	Op-Amp	Bipolar		0.030	8	6.54	0.01	0.378	1.331	7532	41.5 63	35
74LS138	Decoder	LSTTL	1.00	0.037	16	6.54	0.01	0.335	1.210	6373	42.E 175	35
AD940	DC/DC Convertor	Bipolar	1.00	0.141	5	6.54	0.01	2.099	3.044	10429	53.3 190	35
MP298	PGA		1.00	0.338	24							
MP8018A	A/D Convertor		1.00	1.418	52							

CB8 Failure Rate 3.521

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thjc	P	Pi V	C2	Pi E	Pi L
25	1.000	1	0.019	0.38	1
50	0.042	1	0.0051	0.38	1
40	0.192	1	0.008	0.38	1
40	0.192	1	0.008	0.38	1
40	0.192	1	0.008	0.38	1
40	0.212	1	0.0080	0.38	1
40	0.212	1	0.0080	0.38	1
25	0.550	1	0.019	0.38	1
5	0.058	1	0.0061	0.38	1
40	0.236	1	0.012	0.38	1
50	0.158	1	0.0051	0.38	1
40	0.600	1	0.008	0.38	1
50	0.131	1	0.002	0.38	1
50	0.158	1	0.0061	0.38	1
10	1.839	1	0.00145	0.38	1

APPENDIX C
Circuit Board 8: Programmable Gain Amplifier
MIL-HDBK-217E Reliability Prediction
============================ With Adjusted Pi Factors
INTEGRATED CIRCUITS

Name	Function	Type	Usage	Failure Rate	# of Pins	Pi Q	C1	Pi T Pt	X	A	Tj
4052B	Multiplexer	CMOS	1.00	0.038	16	6.54	0.01	0.277	1.017	9270	35.075
LF 412 CN	Op Amp	Bipolar	1.00	0.034	8	6.54	0.01	0.418	1.431	10429	37.700
DAC-08E	D/A Convertor	Bipolar	1.00	0.044	16	6.54	0.01	0.373	1.317	10429	36.650
AM25L03PC	Suc. App. Reg.	TTL	1.00	0.035	16	6.54	0.01	0.238	0.865	5214	40.500
74HCT273	Oct D Flip-Flop	CMOS	1.00	0.044	20	6.54	0.01	0.279	1.026	9270	35.160
4053B	Triple 2 Ch Mux	CMOS	1.00	0.038	16	6.54	0.01	0.277	1.017	9270	35.075
4093B	Schmitt Trigger	CMOS	1.00	0.036	14	6.54	0.01	0.300	1.098	9270	35.900
LM308A	Op Amp	Bipolar	1.00	0.029	8	6.54	0.01	0.319	1.161	10429	35.225
4051B	8 Ch Analog Mux	CMOS	1.00	0.038	16	6.54	0.01	0.277	1.017	9270	35.075

PGA Failure Rate 0.338

Tc	thjc	P	Pi V	C2	Pi E	Pi L
35	50	0.001	1	0.0061	0.5	1
35	50	0.054	1	0.002	0.5	1
35	50	0.033	1	0.0061	0.5	1
35	50	0.11	1	0.0061	0.5	1
35	40	0.004	1	0.008	0.5	1
35	50	0.0015	1	0.0061	0.5	1
35	50	0.018	1	0.0051	0.5	1
35	50	0.0045	1	0.0026	0.5	1
35	50	0.001	1	0.0061	0.5	1

Appendix D. AT&T Failure Rate Predictions of CBA and CBB

APPENDIX D
Circuit Board A: AT&T Reliability Manual Prediction
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INTEGRATED CIRCUITS

8.617E-05 eV / deg K
35 deg C
Environmental Application Factor 1.0

Both Versions of CBA

Name	Function	Type	Failure Rate (10^6 Hrs)	Long-term Hazard Rate (FITs)	Temperature Acc. Factor	Activation Energy, eV	Hazard Rate Multiplier
LM339N	Quad Comparator	Bipolar	0.142	50	0.786	0.4	3.60
74LS154	Decoder	LSTTL	0.028	10	0.786	0.4	3.60
74LS32	Quad OR	LSTTL	0.028	10	0.786	0.4	3.60
74LS02	Quad NOR	LSTTL	0.028	10	0.786	0.4	3.60
74LS08	Quad AND	LSTTL	0.028	10	0.786	0.4	3.60
74LS139	Decoder	LSTTL	0.028	10	0.786	0.4	3.60
AD940	DC/DC Convertor	Bipolar	1.440				
74LS175	Quad D-FF Latch	LSTTL	0.028	10	0.786	0.4	3.60
74LS244	Octal Buffer	LSTTL	0.028	10	0.786	0.4	3.60
74LS244	Octal Buffer	LSTTL	0.028	10	0.786	0.4	3.60
74LS244	Octal Buffer	LSTTL	0.028	10	0.786	0.4	3.60
74LS244	Octal Buffer	LSTTL	0.028	10	0.786	0.4	3.60
74LS14	Hex Invertor (ST)	LSTTL	0.028	10	0.786	0.4	3.60
74LS245	Octal Bus Tranceiver	LSTTL	0.028	10	0.786	0.4	3.60
74LS373	Octal Latch	LSTTL	0.028	10	0.786	0.4	3.60
MP8018A	A/D Convertor	Hybrid	1.722				
8255A-5	Intel PPI	NMOS	0.167	75	0.740	0.5	3.00
8259A	Intel PIC	NMOS	0.167	75	0.740	0.5	3.00
8253	Prog Intrv Tmr	HMOS	0.167	75	0.740	0.5	3.00
8085	CPU	HMOS	0.222	100	0.740	0.5	3.00
HM6116P-4	2K x 8 RAM	CMOS	0.222	100	0.740	0.5	3.00
HM6116P-4	2K x 8 RAM	CMOS	0.222	100	0.740	0.5	3.00
HM6264-LP15	8K x 8 RAM	CMOS	0.444	200	0.740	0.5	3.00
27C64-3	8K x 8 EPROM	CMOS	0.222	100	0.740	0.5	3.00
74LS04	Hex Invertor	LSTTL	0.024	10	0.786	0.4	3.00
UA78H05ASC	Voltage Regulator	Bipolar	0.142	50	0.786	0.4	3.60

Version 2 Only Components
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Name	Function	Type	Failure Rate				
74LS373	Octal Latch	LSTTL	0.028	10	0.786	0.4	3.60
74LS244	Octal Buffer	LSTTL	0.028	10	0.786	0.4	3.60
7406	Hex Invertor	TTL	0.028	10	0.786	0.4	3.60
80C31	8 Bit uController	CMOS	0.222	100	0.740	0.5	3.00
74HC14	Hex Invertor	CMOS	0.024	10	0.786	0.4	3.00
MC3479P	Stepper Driver	Bipolar	0.142	50	0.786	0.4	3.60

Version 1 of CBA Failure Rate 5.669
Version 2 of CBA Failure Rate 6.141

APPENDIX D

Circuit Board B: AT&T Reliability Manual Prediction

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INTEGRATED CIRCUITS

Name	Function	Type	Failure Rate (10^6 Hrs)	Long-term Hazard Rate (FITs)	Temperature Acc. Factor	Activation Energy, eV	Hazard Rate Multiplier
MC6802	Microprocessor	HMOS	0.236	100	0.786	0.4	3.00
74LS32	Quad OR	LSTTL	0.028	10	0.786	0.4	3.60
74LS244	Octal Buffer	LSTTL	0.028	10	0.786	0.4	3.60
74LS244	Octal Buffer	LSTTL	0.028	10	0.786	0.4	3.60
74LS244	Octal Buffer	LSTTL	0.028	10	0.786	0.4	3.60
74LS240	Octal Invertor/Drvr	LSTTL	0.028	10	0.786	0.4	3.60
74LS240	Octal Invertor/Drvr	LSTTL	0.028	10	0.786	0.4	3.60
MC6821	PIA	NMOS	0.167	75	0.740	0.5	3.00
74LS139	Decoder	LSTTL	0.028	10	0.786	0.4	3.60
HM6264-LP15	8K x 8 RAM	CMOS	0.444	200	0.740	0.5	3.00
LM339N	Quad Comparator	Bipolar	0.142	50	0.786	0.4	3.60
74HCT374	Octal Latch	CMOS	0.067	30	0.740	0.5	3.00
PMI OP-07EJ	Op-Amp	Bipolar	0.133	50	0.740	0.5	3.60
74LS138	Decoder	LSTTL	0.028	10	0.786	0.4	3.60
AD940	DC/DC Convertor	Bipolar	0.000				3.60
MP298	PGA		0.886				
MP8018A	A/D Convertor		1.722				
	CBB Failure Rate		4.022				

APPENDIX D

CBA and CBB A/D Convertor AT&T Reliability Manual Prediction

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INTEGRATED CIRCUITS

Boltzmann Constant 8.617E-05 eV / degK
Temperature 35 deg C
Environmental Application Factor 1.0

Name	Function	Type	Usage	Failure Rate (10^6 Hrs)	Long-term Hazard Rate (FITs)	Temperature Acc. Factor	Activation Energy, eV	Hazard Rate Multiplier
LF411	Op Amp	Bipolar	1.00	0.142	50	0.786	0.4	3.60
OP27GP	Op Amp	Bipolar	1.00	0.142	50	0.786	0.4	3.60
OP27GP	Op Amp	Bipolar	1.00	0.142	50	0.786	0.4	3.60
LM301A	Op Amp	Bipolar	1.00	0.142	50	0.786	0.4	3.60
LM319	Dual Comparator	Bipolar	1.00	0.142	50	0.786	0.4	3.60
74LS04	Hex Invertor	LSTTL	1.00	0.028	10	0.786	0.4	3.60
74LS08	Quad AND	LSTTL	1.00	0.028	10	0.786	0.4	3.60
74LS51	Dual AND-OR	LSTTL	1.00	0.028	10	0.786	0.4	3.60
74LS74	Dual D-Flip Flop	LSTTL	1.00	0.028	10	0.786	0.4	3.60
74LS74	Dual D-Flip Flop	LSTTL	1.00	0.028	10	0.786	0.4	3.60
74LS74	Dual D-Flip Flop	LSTTL	1.00	0.028	10	0.786	0.4	3.60
74LS138	3 to 8 Decoder	LSTTL	1.00	0.028	10	0.786	0.4	3.60
74LS151	Multiplexer	LSTTL	1.00	0.028	10	0.786	0.4	3.60
74LS161	Counter	LSTTL	1.00	0.028	10	0.786	0.4	3.60
74LS161	Counter	LSTTL	1.00	0.028	10	0.786	0.4	3.60
74LS164	Shift Register	LSTTL	1.00	0.028	10	0.786	0.4	3.60
74LS169	Counter	LSTTL	1.00	0.028	10	0.786	0.4	3.60
74LS175	Quad D-Flip Flop	LSTTL	1.00	0.028	10	0.786	0.4	3.60
74LS374	Octal Latch	LSTTL	1.00	0.028	10	0.786	0.4	3.60
74LS590	Counter	LSTTL	1.00	0.028	10	0.786	0.4	3.60
74LS697	Counter	LSTTL	1.00	0.028	10	0.786	0.4	3.60
74LS697	Counter	LSTTL	1.00	0.028	10	0.786	0.4	3.60
HI201	Quad Switch	CMOS	1.00	0.067	30	0.740	0.5	3.00
HI201	Quad Switch	CMOS	1.00	0.067	30	0.740	0.5	3.00
74HCT4040	Counter	CMOS	1.00	0.067	30	0.740	0.5	3.00
ICM7209	Clock Generator	CMOS	1.00	0.067	30	0.740	0.5	3.00
SD211	Quad Switch	CMOS	1.00	0.067	30	0.740	0.5	3.00
"	Quad Switch	CMOS	1.00	0.067	30	0.740	0.5	3.00
IMF6485	Dual Amp	JFET	1.00	0.133	50	0.740	0.5	3.60

A/D Convertor Failure Rate 1.72[illegible]

APPENDIX D

Circuit Board B Programmable Gain Amplifier AT&T Reliability Manual Prediction

INTEGRATED CIRCUITS

Name	Function	Type	Usage	Failure Rate (10^6 Hrs)	Long-term Hazard Rate (FITs)	Temperature Acc. Factor	Activation Energy, eV	Hazard Rate Multiplier
4052B	Multiplexer	CMOS	1.00	0.167	75	0.740	0.5	3.00
LF 412 CN	Op Amp	Bipolar	1.00	0.142	50	0.786	0.4	3.60
DAC-08E	D/A Convertor	Bipolar	1.00	0.142	50	0.786	0.4	3.60
AM25L03PC	Suc. App. Reg.	TTL	1.00	0.020	10	0.786	0.4	3.60
74HCT273	Oct D Flip-Flop	CMOS	1.00	0.067	30	0.740	0.5	3.00
4053B	Triple 2 Ch Mux	CMOS	1.00	0.067	30	0.740	0.5	3.00
4093B	Schmitt Trigger	CMOS	1.00	0.067	30	0.740	0.5	3.00
LM308A	Op Amp	Bipolar	1.00	0.142	50	0.786	0.4	3.60
4051B	8 Ch Analog Mux	CMOS	1.00	0.067	30	0.740	0.5	3.00

PGA Failure Rate 0.886

APPENDIX E
Circuit Board A: Reliability Prediction 5-9-91
Using National Semiconductor, Motorola Corporation, Intel Corp., and Texas Instruments Data

INTEGRATED CIRCUITS

Boltzmann Constant	8.6170E-05 eV/deg K	
Temperature	35 deg C	
Activation Energies:	0.4 eV,	National Semiconductor
	0.96 eV,	Texas Instruments
Acceleration Factors	30.1	National Semiconductor
	9.1	Texas Instruments

Name	Function	Type	CBA Failure Rate	Motorola Failure Rate	National Failure Rate	Texas Inst. Failure Rate	National Base Failure Rate @125 deg C
LM339N	Quad Comparator	Bipolar	0.146			0.146	
74LS154	Decoder	LSTTL	0.043		0.018	0.068	5.32E-07
74LS32	Quad OR	LSTTL	0.043		0.018	0.068	5.32E-07
74LS02	Quad NOR	LSTTL	0.043		0.018	0.068	5.32E-07
74LS08	Quad AND	LSTTL	0.043		0.018	0.068	5.32E-07
74LS139	Decoder	LSTTL	0.043		0.018	0.068	5.32E-07
A0940	DC/DC Convertor	Bipolar	1.440		1.440		
74LS175	Quad D-FF Latch	LSTTL	0.043		0.018	0.068	5.32E-07
74LS244	Octal Buffer	LSTTL	0.043		0.018	0.068	5.32E-07
74LS244	Octal Buffer	LSTTL	0.043		0.018	0.068	5.32E-07
74LS244	Octal Buffer	LSTTL	0.043		0.018	0.068	5.32E-07
74LS244	Octal Buffer	LSTTL	0.043		0.018	0.068	5.32E-07
74LS14	Hex Invertor (ST)	LSTTL	0.043		0.018	0.068	5.32E-07
74LS245	Octal Bus Tranceiver	LSTTL	0.043		0.018	0.068	5.32E-07
74LS373	Octal Latch	LSTTL	0.043		0.018	0.068	5.32E-07
MP8018A	A/D Convertor	Hybrid	1.110				
8255A-5	Intel PPI	NMOS	0.297	0.297			
8259A	Intel PIC	NMOS	0.297	0.297			
8253	Prog Intrv Tmr	HMOS	0.408	0.408			
8085	CPU	HMOS	0.408	0.408			
HM6116P-4	2K x 8 RAM	CMOS	0.227	0.227			
HM6116P-4	2K x 8 RAM	CMOS	0.227	0.227			
HM6264-LP15	8K x 8 RAM	CMOS	0.227	0.227			
27C64-3	8K x 8 EPROM	CMOS	0.227	0.227			
74LS04	Hex Invertor	LSTTL	0.043		0.018	0.068	5.32E-07
UA78H05ASC	Voltage Regulator	Bipolar	0.041		0.060	0.021	1.82E-06

Texas Inst. Base Failure Rate @55 deg C
1.32E-06
6.15E-07
6.15E-07
6.15E-07
6.15E-07
6.15E-07
6.15E-07
6.15E-07
6.15E-07
6.15E-07
6.15E-07
6.15E-07
6.15E-07
6.15E-07
6.15E-07
1.90E-07

APPENDIX E

Circuit Board 8: Reliability Prediction Using National Semiconductor, Motorola Corporation, and Texas Instruments Data

INTEGRATED CIRCUITS

Boltzmann Constant	8.6170E-05 eV/deg K	
Temperature	35 deg C	
Activation Energies:	0.4 eV,	National Semiconductor
	0.96 eV,	Texas Instruments
Acceleration Factors	30.1	National Semiconductor
	9.1	Texas Instruments

Name	Function	Type	C88 Failure Rate	Motorola Failure Rate	National Failure Rate	Texas Inst. Failure Rate	National Base Failure Rate @125 deg C
MC6802	Microprocessor	HMOS	0.408	0.408			
74LS32	Quad OR	LSTTL	0.043		0.018	0.068	5.32E-07
74LS244	Octal Buffer	LSTTL	0.043		0.018	0.068	5.32E-07
74LS244	Octal Buffer	LSTTL	0.043		0.018	0.068	5.32E-07
74LS244	Octal Buffer	LSTTL	0.043		0.018	0.068	5.32E-07
74LS240	Octal Invertor/Drvr	LSTTL	0.043		0.018	0.068	5.32E-07
74LS240	Octal Invertor/Drvr	LSTTL	0.043		0.018	0.068	5.32E-07
MC6821	PIA	NMOS	0.297	0.297			
74LS139	Decoder	LSTTL	0.043		0.018	0.068	5.32E-07
HM6264-LP15	8K x 8 RAM	CMOS	0.157	0.227	0.086		2.59E-06
LM339N	Quad Comparator	Bipolar	0.168		0.189	0.146	5.70E-06
74HCT374	Octal Latch	CMOS	0.013		0.013		4.01E-07
PMI OP-07EJ	Op-Amp	Bipolar	0.307		0.189	0.424	5.70E-06
74LS138	Decoder	LSTTL	0.043		0.018	0.068	5.32E-07
AD940	DC/DC Convertor	Bipolar	0.424			0.424	
MP298	PGA	Hybrid	0.705				
MP8018A	A/D Convertor	Hybrid	1.110				

C88 Failure Rate 3.931

Texas Inst. Base Failure Rate @55 deg C
6.15E-07
6.15E-07
6.15E-07
6.15E-07
6.15E-07
6.15E-07
6.15E-07
1.32E-06
3.84E-06
6.15E-07
3.84E-06

A/D Convertor Reliability Prediction
========================= Using National Semiconductor Data
Intel Corp. , and Texas Instruments Data

INTEGRATED CIRCUITS

Boltzmann Constant	8.6170E-05 eV/deg K	
Temperature	35 deg C	
Activation Energies:	0.4 eV,	National Semiconductor
	0.96 eV,	Texas Instruments
Acceleration Factors:	30.1	National Semiconductor
	9.1	Texas Instruments

Name	Function	Type	CBB Failure Rate	National Failure Rate	Texas Inst. Failure Rate	National Base Failure Rate @125 deg C	Texas Inst. Base Failure Rate @55 deg C
LF411	Op Amp	Bipolar	0.032		0.032		2.90E-07
OP27GP	Op Amp	Bipolar	0.032		0.032		2.90E-07
OP27GP	Op Amp	Bipolar	0.032		0.032		2.90E-07
LM301A	Op Amp	Bipolar	0.032		0.032		2.90E-07
LM319	Dual Comparator	Bipolar	0.146		0.146		1.32E-06
74LS04	Hex Invertor	LSTTL	0.043	0.018	0.068	5.32E-07	6.15E-07
74LS08	Quad AND	LSTTL	0.043	0.018	0.068	5.32E-07	6.15E-07
74LS51	Dual AND-OR	LSTTL	0.043	0.018	0.068	5.32E-07	6.15E-07
74LS74	Dual D-Flip Flop	LSTTL	0.043	0.018	0.068	5.32E-07	6.15E-07
74LS74	Dual D-Flip Flop	LSTTL	0.043	0.018	0.068	5.32E-07	6.15E-07
74LS74	Dual D-Flip Flop	LSTTL	0.043	0.018	0.068	5.32E-07	6.15E-07
74LS138	3 to 8 Decoder	LSTTL	0.043	0.018	0.068	5.32E-07	6.15E-07
74LS151	Multiplexer	LSTTL	0.043	0.018	0.068	5.32E-07	6.15E-07
74LS161	Counter	LSTTL	0.043	0.018	0.068	5.32E-07	6.15E-07
74LS161	Counter	LSTTL	0.043	0.018	0.068	5.32E-07	6.15E-07
74LS164	Shift Register	LSTTL	0.043	0.018	0.068	5.32E-07	6.15E-07
74LS169	Counter	LSTTL	0.043	0.018	0.068	5.32E-07	6.15E-07
74LS175	Quad D-Flip Flop	LSTTL	0.043	0.018	0.068	5.32E-07	6.15E-07
74LS374	Octal Latch	LSTTL	0.043	0.018	0.068	5.32E-07	6.15E-07
74LS590	Counter	LSTTL	0.043	0.010	0.068	5.32E-07	6.15E-07
74LS697	Counter	LSTTL	0.043	0.018	0.068	5.32E-07	6.15E-07
74LS697	Counter	LSTTL	0.043	0.018	0.068	5.32E-07	6.15E-07
HI201	Quad Switch	CMOS	0.013	0.013		4.01E-07	
HI201	Quad Switch	CMOS	0.013	0.013		4.01E-07	
74HCT4040	Counter	CMOS	0.013	0.013		4.01E-07	
ICM7209	Clock Generator	CMOS	0.013	0.013		4.01E-07	
SD211	Quad Switch	CMOS	0.013	0.013		4.01E-07	
"	Quad Switch	CMOS	0.013	0.013		4.01E-07	
IMF6485	Dual Amp	JFET	0.028	0.028		8.55E-07	
	Adjusted Failure Rate		1.110				

Programmable Gain Amplifier Reliability Prediction
Using National Semiconductor Data
Intel Corp., and Texas Instruments Data

INTEGRATED CIRCUITS

Boltzmann Constant	8.6170E-05 eV/deg K	
Temperature	35 deg C	
Activation Energies:	0.4 eV,	National Semiconductor
	0.96 eV,	Texas Instruments
Acceleration Factors:	30.1	National Semiconductor
	9.1	Texas Instruments

Name	Function	Type	PGA Failure Rate	National Failure Rate	Texas Inst. Failure @125 deg C	National Base Failure Rate @125 deg C	Texas Inst. Base Failure Rate @55 deg C
4052B	Multiplexer	CMOS	0.013	0.013		4.01E-07	
LF 412 CN	Op Amp	Bipolar	0.111	0.189	0.032	5.70E-06	2.90E-07
DAC-08E	D/A Converter	Bipolar	0.307	0.189	0.424	5.70E-06	3.84E-06
AM25L03PC	Suc. App. Reg.	TTL	0.189	0.189		5.70E-06	
74HCT273	Oct D Flip Flop	CMOS	0.013	0.013		4.01E-07	
4053B	Triple 2 Ch Mux	CMOS	0.013	0.013		4.01E-07	
4093B	Schmitt Trigger	CMOS	0.013	0.013		4.01E-07	
LM308A	Op Amp	Bipolar	0.032		0.032		2.90E-07
4051B	8 Ch Analog Mux	CMOS	0.013	0.013		4.01E-07	
	Predicted Failure Rate		0.705				

Texas Inst. Base Failure Rate @55 deg C
6.15E-07
6.15E-07
1.20E-06
6.43E-07